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EFFECTS OF CLOUD COVER ON SATELLITE POSITIONING

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Albert R. Boehm

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109 Massachusetts Avenue
Lexington, MA 02173

9 November 1992

Scientific Report No. 3

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13. ABSTRACT *(Maximum 200 words)*

This report specifies how cloud cover would affect the Landsat-7 satellite at two different equatorial crossing times, 0945 or 1030 Mean Apparent Sun Time (MAST). Changes in the frequency of cloud cover observed in the two orbits are shown in maps and graphs.

14. SUBJECT TERMS

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EFFECTS OF CLOUD COVER ON SATELLITE POSITIONING

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1. PURPOSE

The purpose of this report is to specify how cloud cover would affect the Landsat-7 satellite at two different equatorial crossing times, 0945 and 1030 Mean Apparent Sun Time (MAST). This 45 minute difference affects the climatic frequency of cloud cover. Changes in the frequency of cloud cover as observed in the two orbits are detailed in this report.

2. DATA

The data used for this analysis come from three sources DOE/NCAR data, Burger data, and NIMBUS-7 CMatrix data.

2a. DOE/NCAR Data

The "Climatological Data For Clouds Over The Globe From Surface Observations" (Hahn, 1987) contains digital global maps of long-term monthly and/or seasonal total cloud cover, cloud type amounts and frequencies of occurrence, low cloud base heights, harmonic analyses of annual and diurnal trends, and frequencies of cloud type occurrences. Most of the data are mapped on grids. Each grid box represents a 5-degree latitude by 5-degree longitude resolution equatorward of 50 degrees latitude. The boxes increase in longitude dimension poleward of 50 degrees latitude creating nearly equal area boxes. According to Hahn (1987), data from all available stations within a grid box were used to compute the average for that box. The data are archived so that the land observed cloud data are stored separately from the ocean observed data. The period of record for land observations is the 11 years from January 1971 through December 1981. The period of record for ship observations is the 54 years from January 1930 through November 1983. The seasonal sky cover data archived at eight times of day (GMT) were the portion of data used.

2b. Burger Data

The Burger data (Burger, 1985) is a climatology of ground-observed sky cover observations recorded over single-point locations for over 2,000 weather reporting stations around the globe. The data are archived for the four mid-season months of January, April, July, and October where 3 hourly averages of sky cover are centered at the four local standard times of 01, 07, 13, and 19 LST. Sky cover data over land areas were extracted over a 28 year period of record from 1945 through 1973.

The Burger data were originally compiled from the Revised Uniform Summaries of Surface Weather Observations (RUSSWO's), Naval Intelligence Survey (NIS), and NAVATLAS records. Willand (1988) reformatted the Burger data for subsequent use in the development of an automated global climatology. the database was further refined by Willand (1991) in order to replace the parameter "scale distance" (Burger, 1984) with the more robust parameter called "mean correlation" (Boehm, 1992).

2c. NIMBUS-7 Data

According to Hwang, et al. (1988), the primary merits of the NIMBUS-7 Cmatrix Cloud data set are: 1) observed radiances used for this cloud data set were obtained from the same instruments used over six continuous years between 1979-1985, so it represents the most homogeneous satellite derived cloud data set available; 2) the cloud data set is efficiently retrieved and stored, so the analysis of global cloud distribution over climatological time scales is feasible; and 3) daily, as well as monthly averages and variances of cloud data are presented together with a correlation coefficient surface temperature archive. Because of these merits, this cloud database was acquired and utilized for defining climatological cloud cover statistics of the earth as viewed from space.

2d. Data Merging

Data from the three sets defined above were first fitted by two parameters, the mean sky cover and the mean correlation. The mean correlation is the arithmetic average of correlation between all possible pairs of points in a domain. It is mathematically related to the standard deviation of the coverage distribution and is a function of the correlation structure.

The mean sky cover and mean correlation as well as sample size and interannual variability were analyzed on the globe by a weighted 14 wave number spectral analysis using a weighted regression matrix inversion to allow for unequally spaced data. Time of day is analyzed with a third order Fourier series.

The sky cover distribution was calculated from the coverage algorithm—CUB (Boehm, 1992) using mean sky cover and mean skydome correlation derived from surface observations which include DOE/NCAR data and Burger data. Next a mean cloud cover probability at a point was calculated using the Malick and Allen (1979) algorithm on each tenth of coverage. Finally, CUB was used to calculate fractional coverage based on the point mean correlation for a specific area size interpolated from NIMBUS-7 data and degrees of freedom set at 80 (found empirically). The mean cloud cover and the fractional coverage frequencies are used in three methods of presentation.

3. DERIVED STATISTICS

3a. Mean Maps

First, maps of mean cloud cover were produced. Cloud cover values were calculated for the specified time. A third order

Fourier analysis was used to obtain cloud cover values for times such as 0945 and 1030 MAST. Time was continually being updated based on the satellite subpoint latitude. Time adjustments for each satellite subpoint latitude are given in Table 1, which was provided by Locke Stuart, NASA Goddard Space Flight Center.

The cloud cover values were calculated at evenly spaced gridpoints. Longitudinally there are 72 gridpoints (spaced 5 degrees apart). Latitudinally there are 33 gridpoints, spaced evenly according to the sine of the latitude. Bilinear interpolation was used for contouring. Maps were created for January, April, July, and October. Also, difference maps were created for the 1030 MAST mean minus the 0945 MAST mean.

Maps of mean cloud cover are presented in figures 1 through 4. The maps are in pairs, where map a (the top map) is the mean cloud cover for the month at 1030 MAST and map b (the lower map) is the difference between the 1030 MAST and 0945 MAST mean cloud cover for the given month. There are four pairs of these maps, one for each mid season month.

3b. Fractional Cloud Cover Frequency Maps

These maps show frequency of cloud cover over the earth given a particular area size, cloud cover threshold, and time. The months and times used are the same as with the mean cloud cover. The area sizes are squares 30 km and 90 km on a side. Cloud cover thresholds are 30% or less, 20% or less, 10% or less, and 0%. Difference maps were produced also for this set of maps. The headers on these maps are abbreviated. For example: JAN-1030-90KM-30% is the frequency of cloud cover less than or equal to 30% at a 1030 MAST equatorial crossing time, during January, using a 90 km cell size.

As with the mean cloud cover maps, the frequency of fractional cloud cover maps are presented in pairs. The frequency maps are found in figures 5 through 8. Map a in each pair is the frequency of 20% or less cloud cover occurring at 1030 MAST in the given month using a 30 kilometer grid size. Map b is the difference of the frequencies between 1030 MAST and 0945 MAST.

3c. Graphs

Graphs at selected locations are the third method of presentation. Each graph shows mean sky cover, probability of cloud cover less than or equal to 30% (for land stations), 20% (for oceanic stations), and 10% (for all locations). These graphs are similar to those in the Steeves and Boehm report (Morning Versus Afternoon EOS-A Orbit). However, these new graphs are based on a larger, more reliable set of data.

Graphs are produced in a manner similar to the maps, but consist of all times (from 0000 MAST to 2400 MAST). Another difference is the use of sky cover instead of cloud cover. Sky cover is a measure of cloudiness over the skydome observed while looking up. Cloud cover is obtained looking down, e.g. from a satellite. The different viewing perspectives cause values of the two to be different.

A list of the areas for graphs are as follows:

Figure No. Jan.	Figure No. Jul.	Location	Latitude	Longitude
9	10	Alabama	33.31	-86.49
11	12	Sahara Desert	23.44	10.00
13	14	Amazonas	-4.15	-64.30
15	16	Indian Ocean	0.00	75.00
17	18	Atlantic Coast	-15.00	-34.00
19	20	Pacific Ocean	-15.00	-105.00
21	22	Pacific Ocean	-30.00	-135.00

- = South, - = West

4. RESULTS AND ANALYSIS

Difference maps give the clearest results. On these maps clear areas indicate less than $\pm$ 1% difference between 0945 and 1030 MAST. Hatched areas as indicated are negative values, with less cloud cover at 1030. Other hatched styles show greater cloud cover at 1030.

The difference maps clearly show that cloud cover changes between 0945 and 1030 MAST vary from location to location. Most regions show marginal change (plus or minus one percent). There is little, if any, change greater than five percent. In several there is less cloud cover observed for the 1030 MAST equatorial crossing than the 0945 equatorial crossing. However, time of year and location affect these values.

5. ERROR ANALYSIS

The original merged cloud data base was closely quality controlled. However, cloud climatologies have several types of errors.

Sampling error is high in cloud climatologies. As a rule, the number of equivalent independent data is about one third the number of days of data. Thus, for the month of January, the Nimbus-7 data with six Januarys has only 6 x 31 / 3 = 62 equivalent independent samples. Surface data has a satisfactory period of record in most of the Northern Hemisphere. But in the Southern Hemisphere, especially south of latitude 60°S, surface data is sparce. Some areas have less than 10 equivalent independent samples.

In the Arctic and Antarctic surface data is sparce and satellite cloud measurements suffer from the fact that cloud and surface radiances are similar both in the visible and infrared.

The parameterization using only the mean and mean correlation yields good results. Mean square errors are about 2%.

Spatial analyses using the weighted spectral analysis technique have about a 0.95 multiple correlation coefficient. At least some of this error is due to the sampling error as opposed to spatial analysis error per se. However, local effects due to terrain, etc.

are not taken into account by this type of analysis. That is, the spatial analysis results are quite good for the average point in a small region, but a particular point may have considerable error.

The above errors refer to values at 0945 or at 1030 MAST. The statistic of interest is the difference in values between the two times. Comparison of the fractional coverage statistics show that the time difference for all the various coverages depends almost entirely on the differences in the mean. Errors in parameterization and sampling error are effectively canceled out. In statistics this effect is sometimes refered to as a paired sample statistic - if there is a similar and highly correlated bias in a pair of statistics, the difference between the statistics will be nearly unbiased.

Therefore the error in the difference is believed to be less than 2% excepting the Arctic and regions south of 60°S latitude.

6. ACKNOWLEDGMENT

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MAP OF JAN-1030-MEAN CLOUD COVER

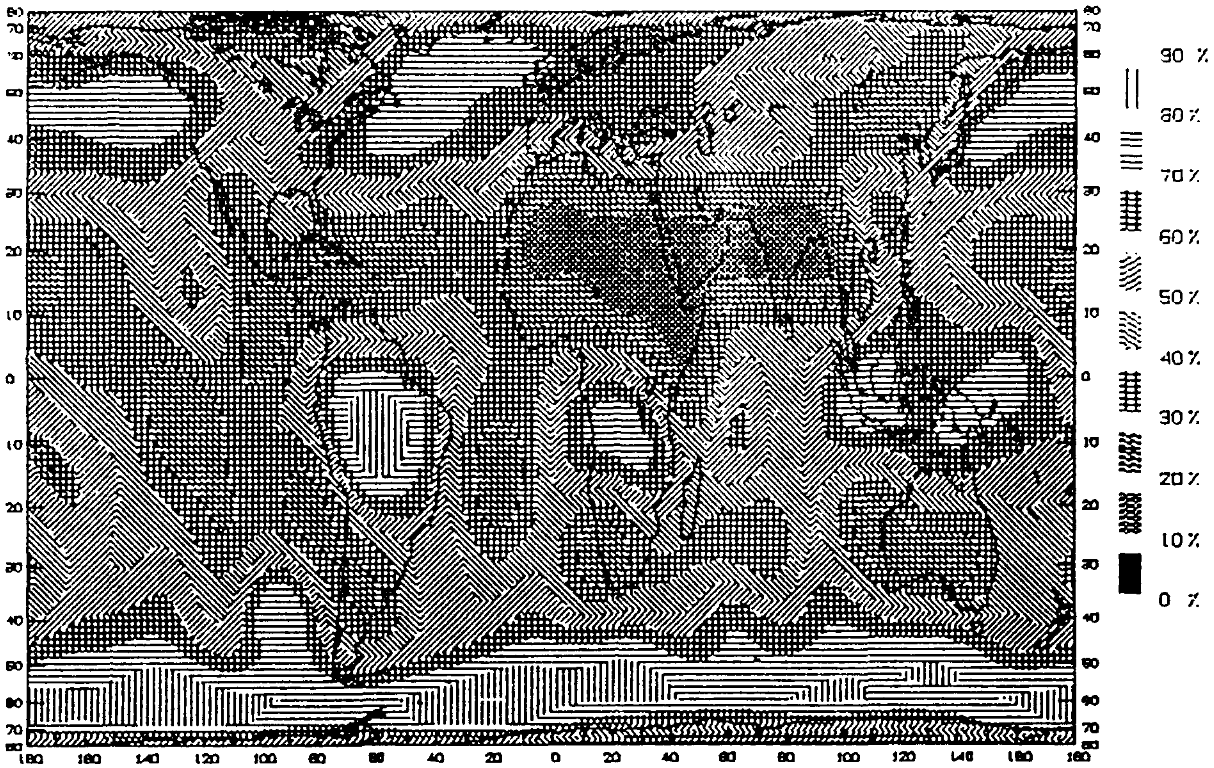


Figure 1a.

MEAN CLOUD COVER DIFFERENCE MAP : JAN-1030-MEAN MINUS JAN-945-MEAN

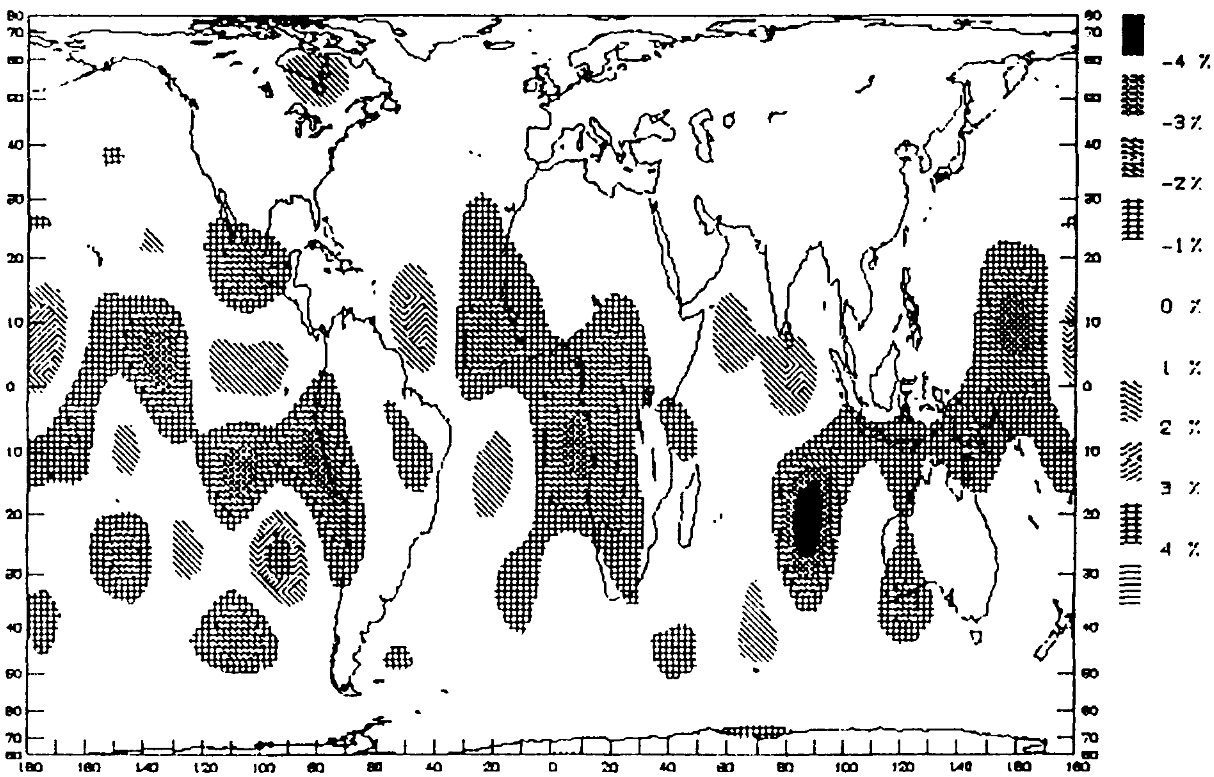
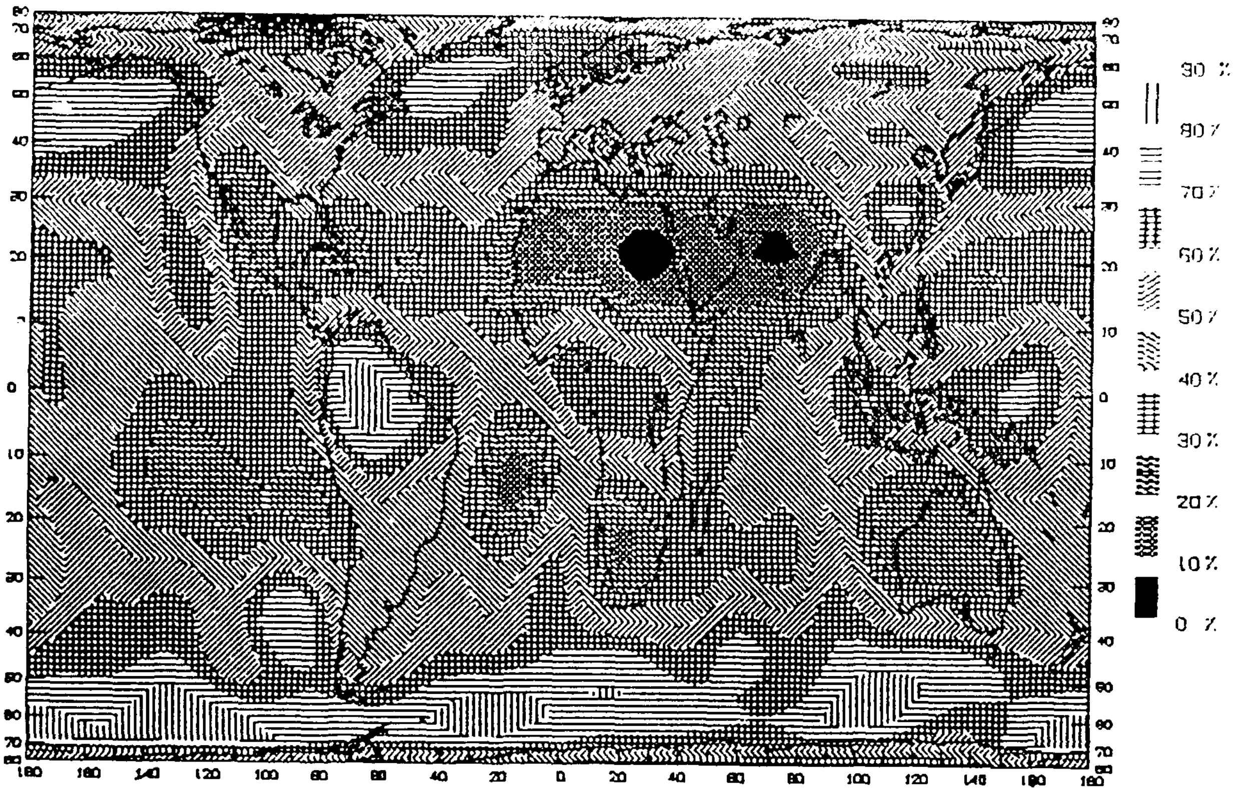


Figure 1b.

MAP OF APR-1030 MEAN CLOUD COVER



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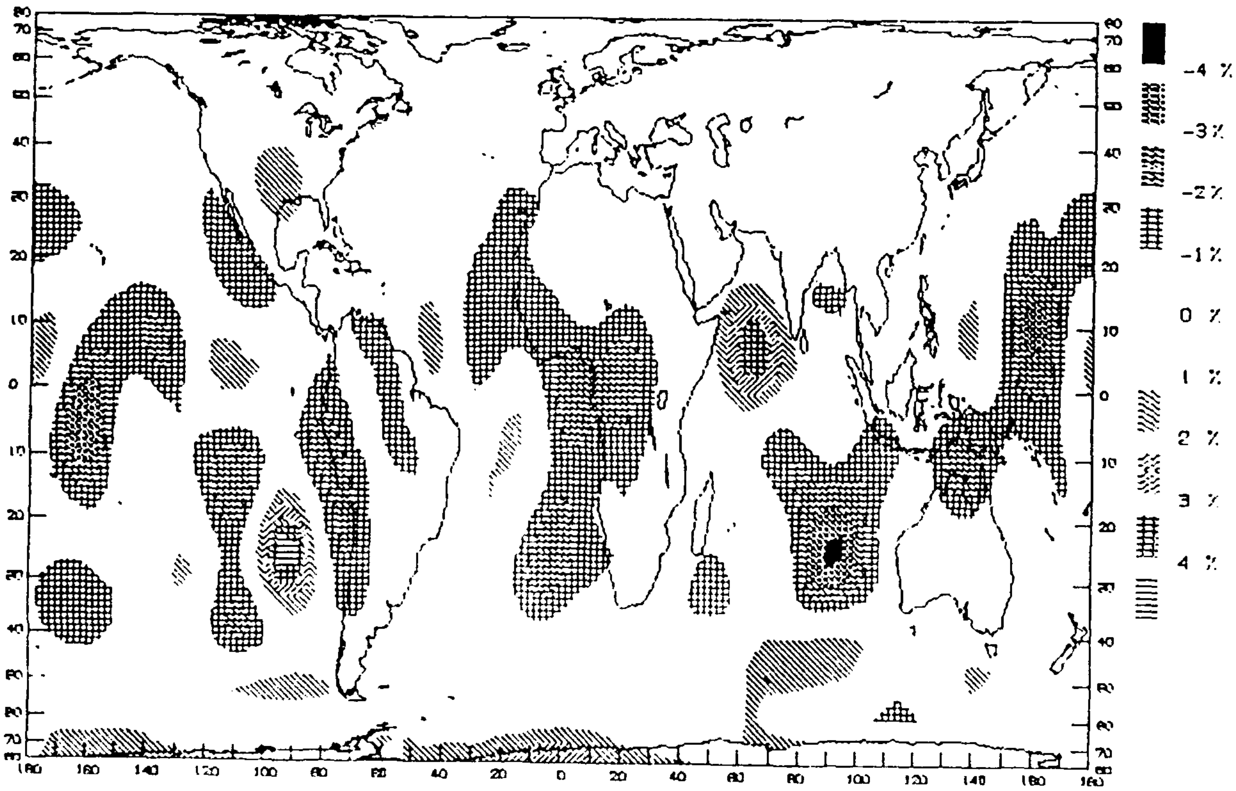

Figure 2b.

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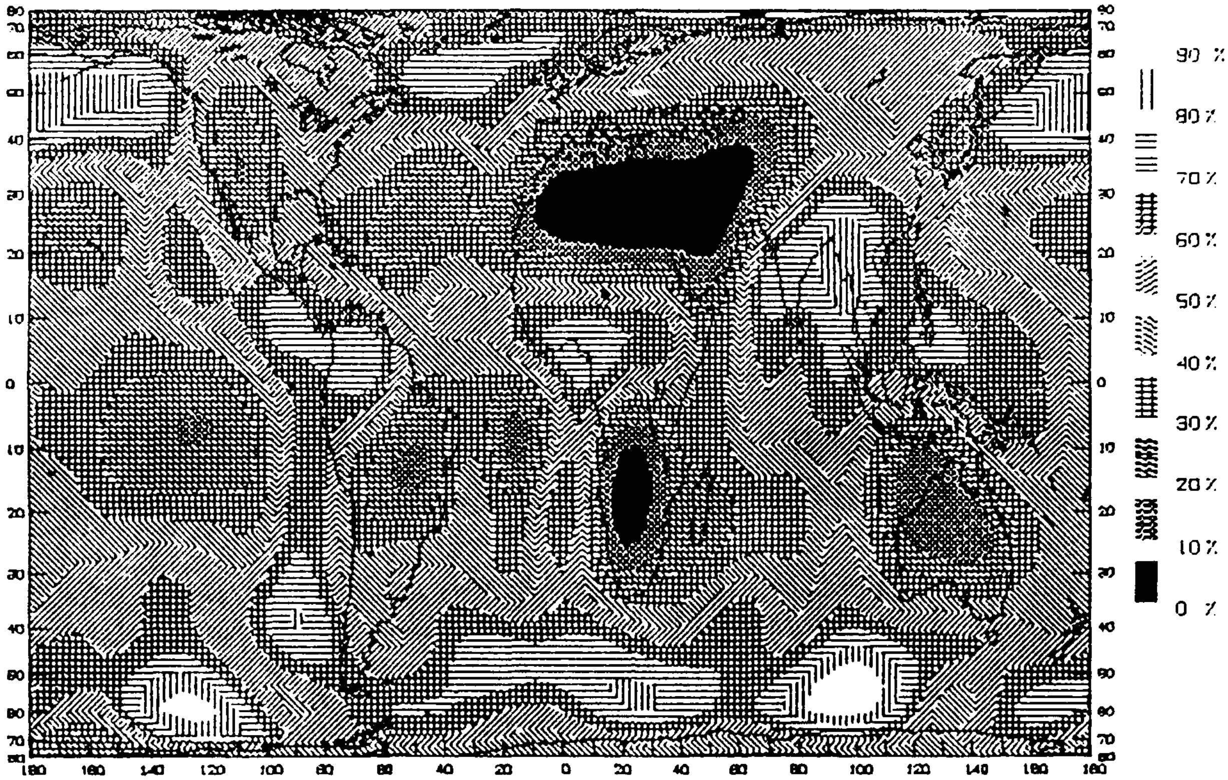

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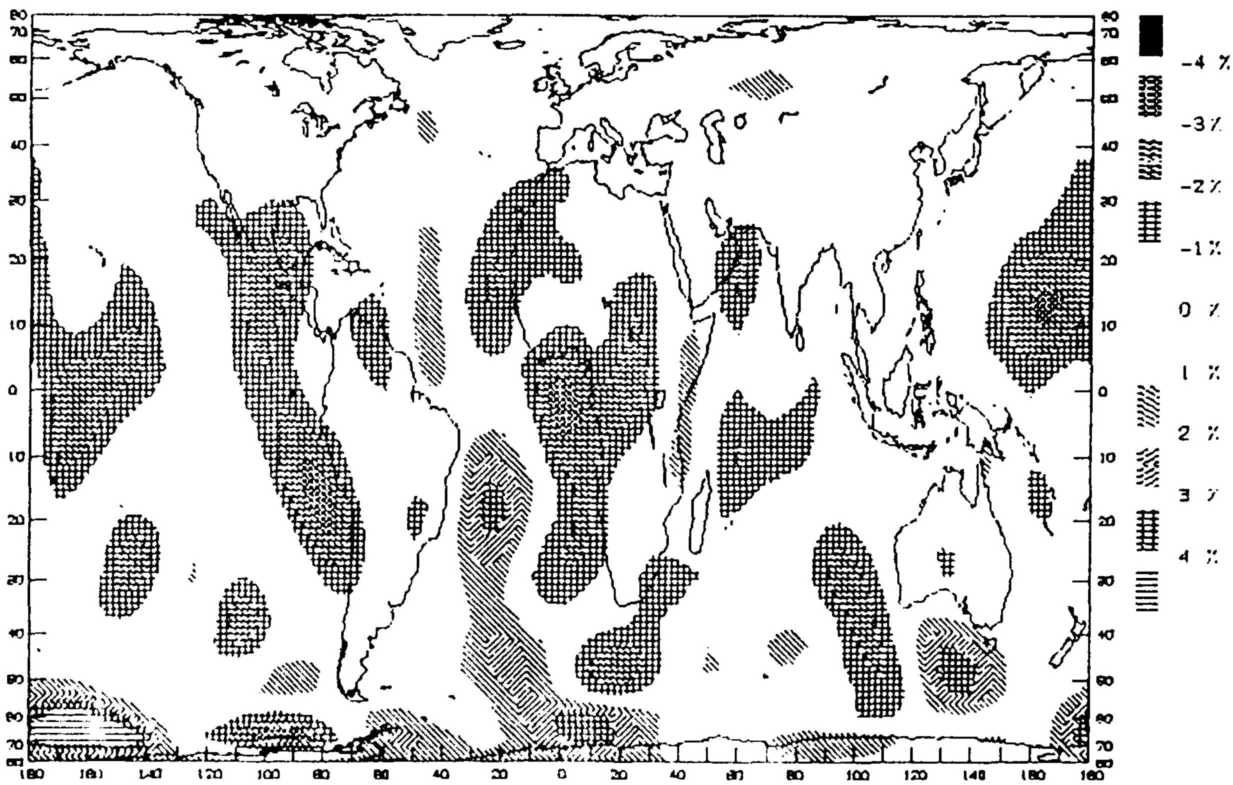

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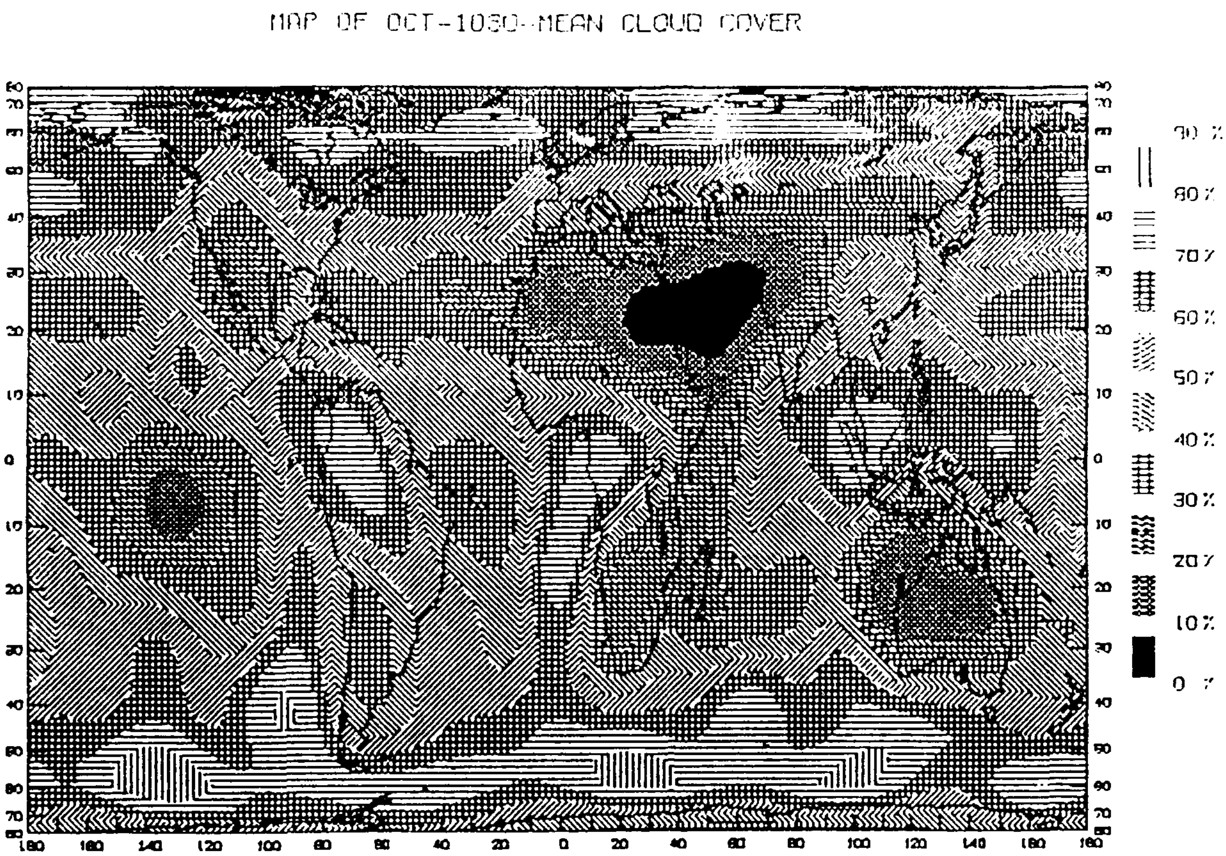

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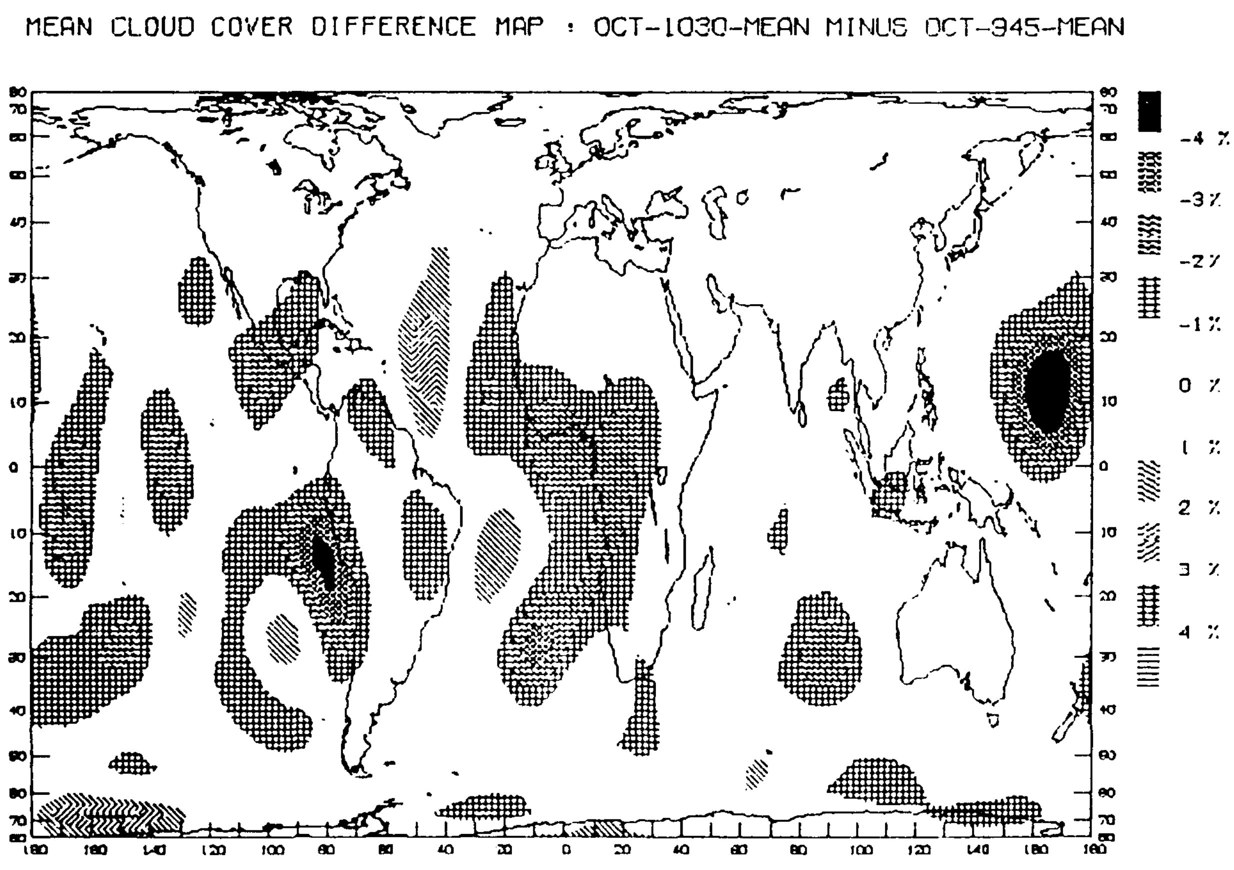

Figure 4b.

PERCENT OCCURENCE MAP FOR : JAN-1030-30KM-20%

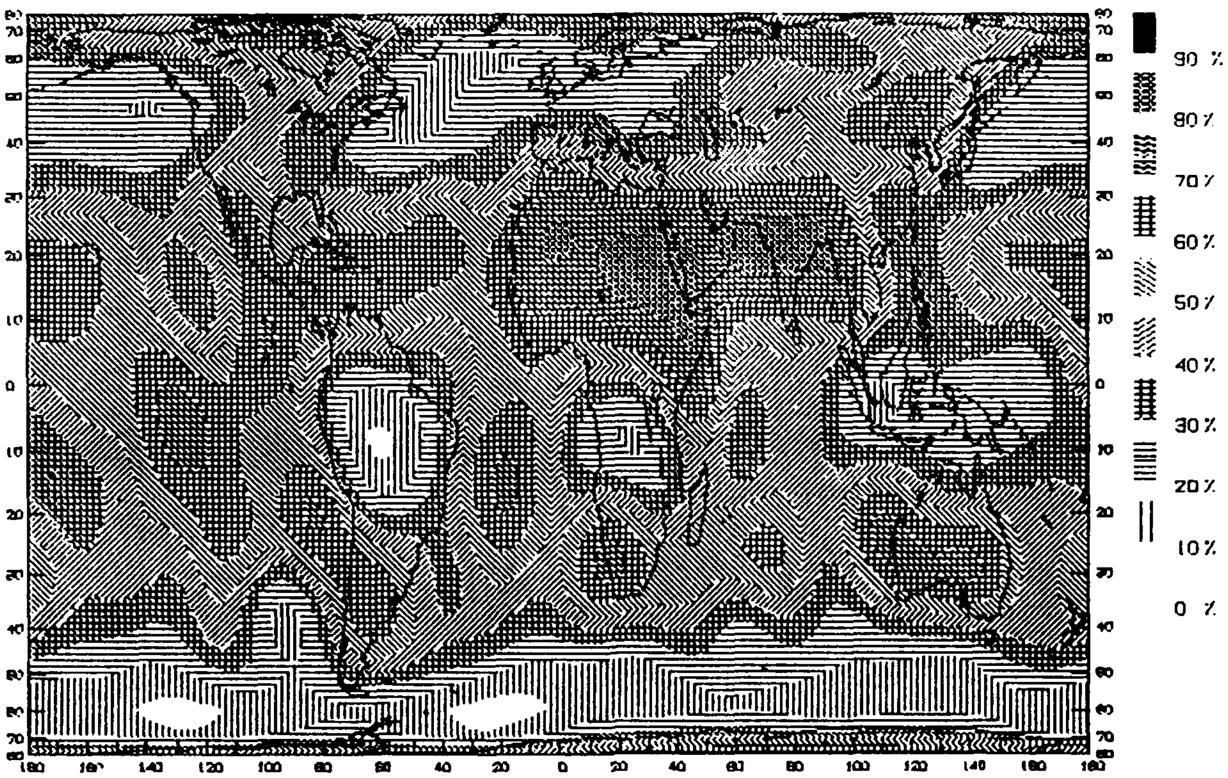

Figure 5a.

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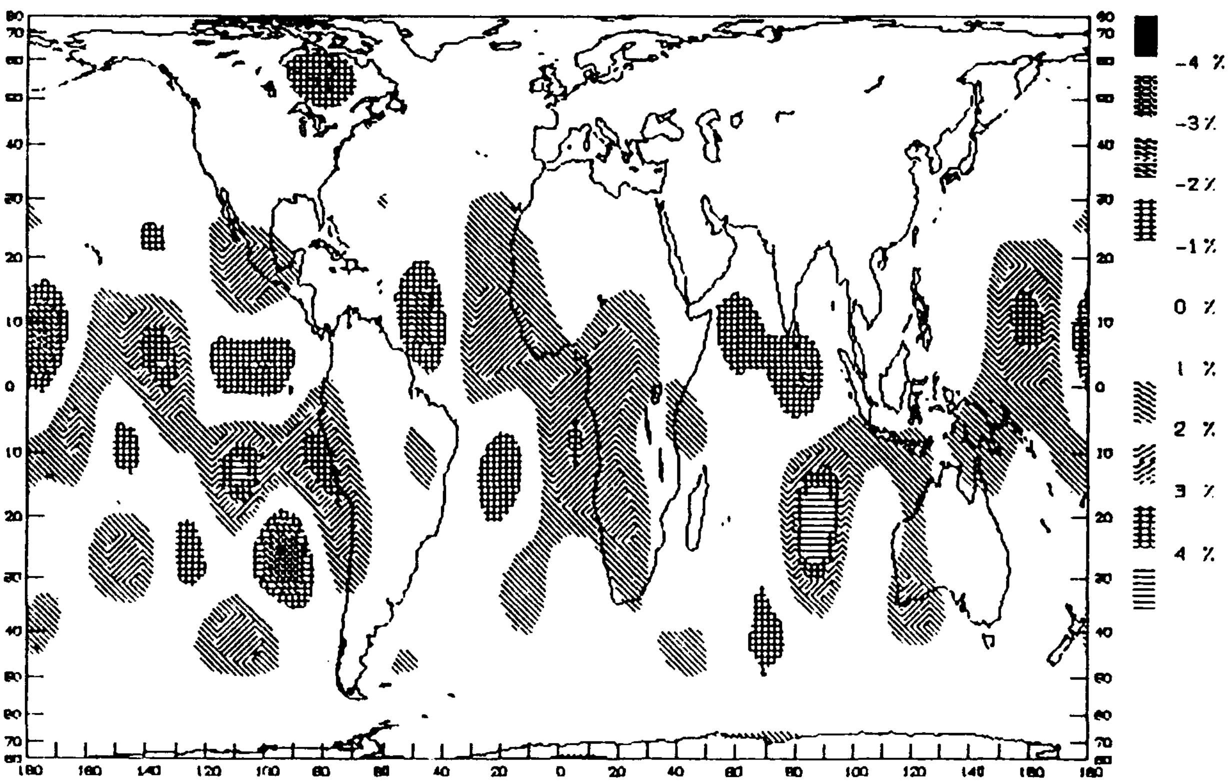

Figure 5b.

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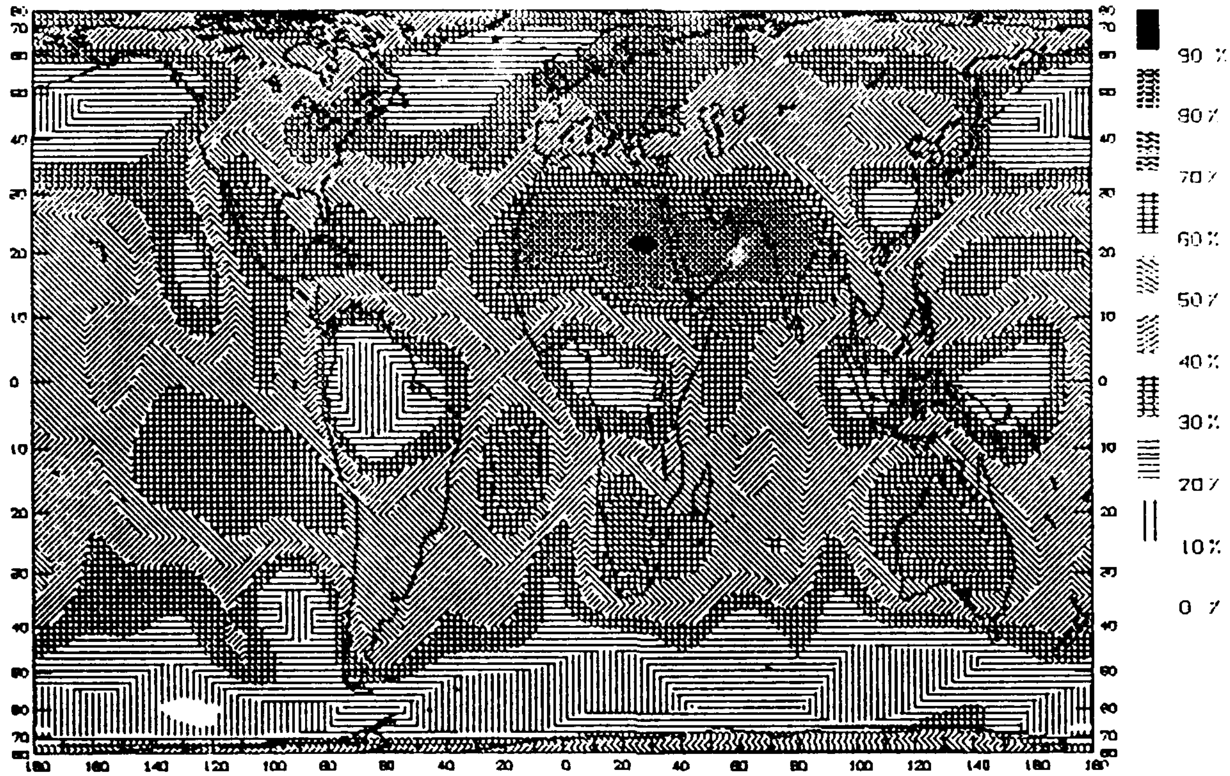

Figure 6a.

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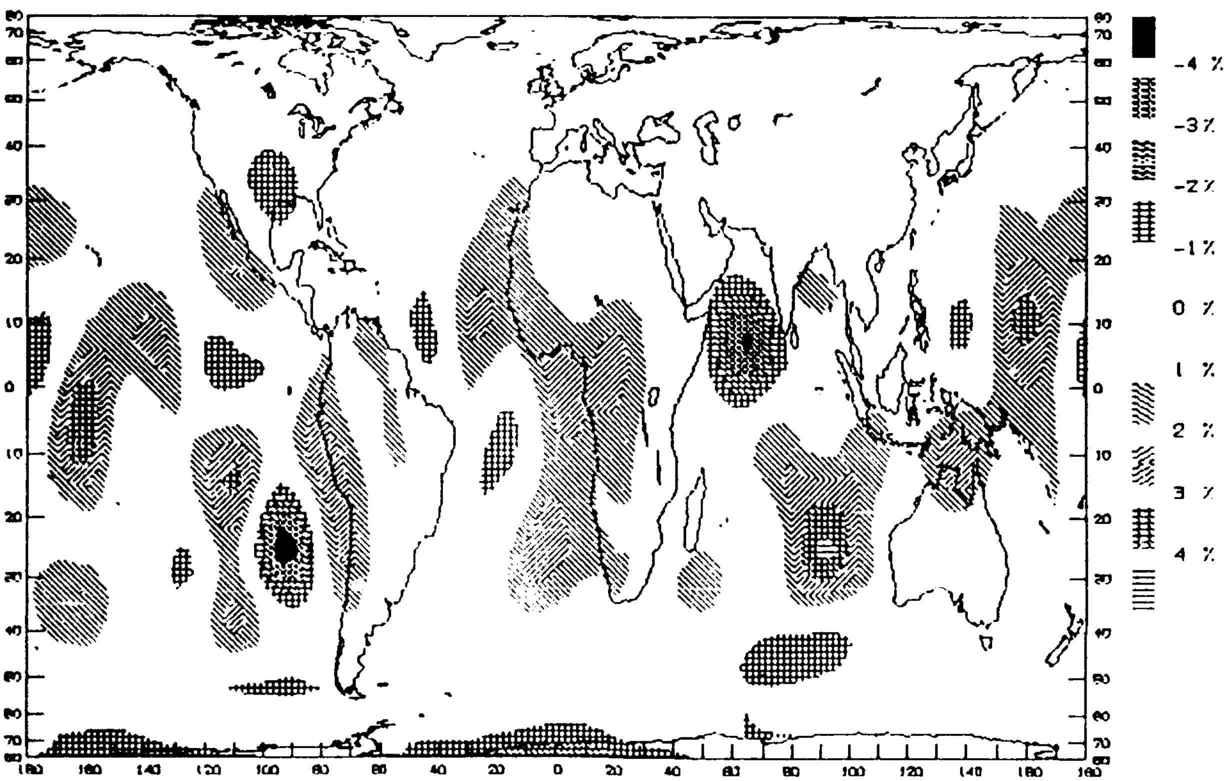

Figure 6b.

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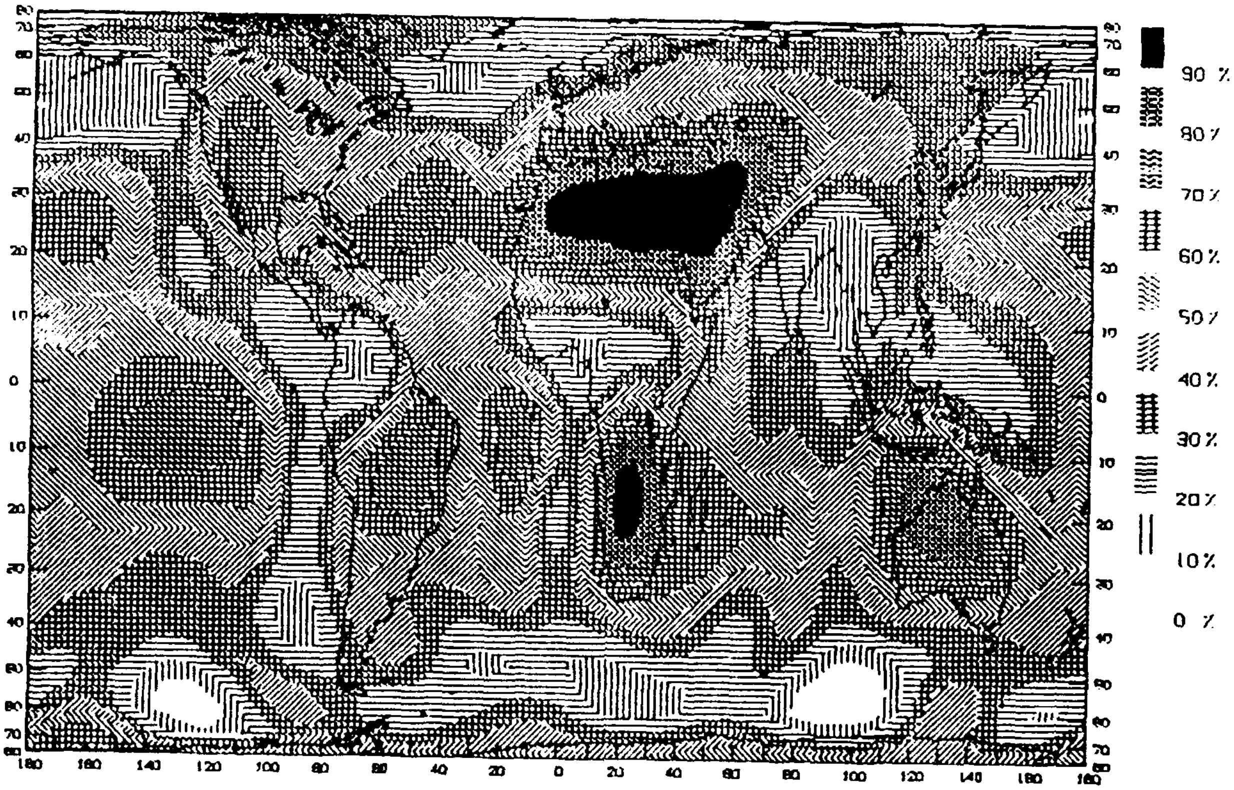

Figure 7a.

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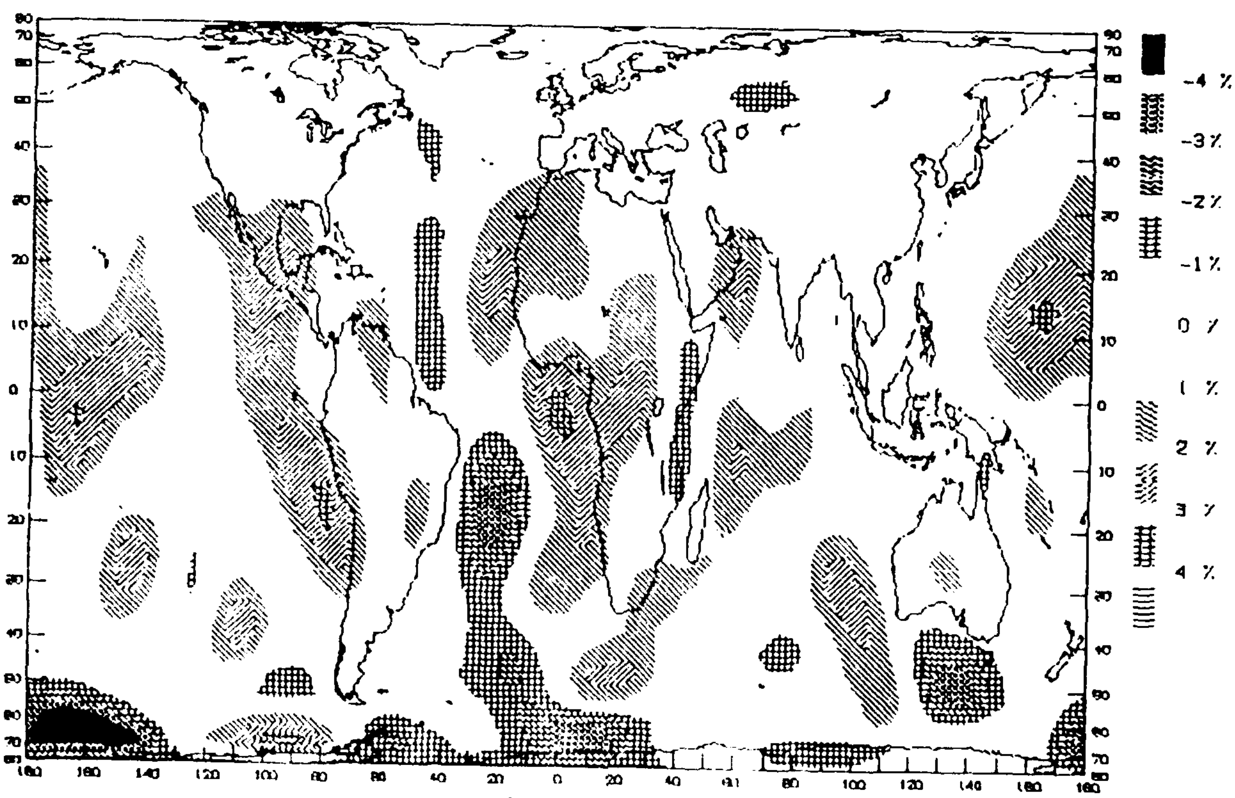

Figure 7b.

PERCENT OCCURENCE MAP FOR : OCT-1030-30KM-20%

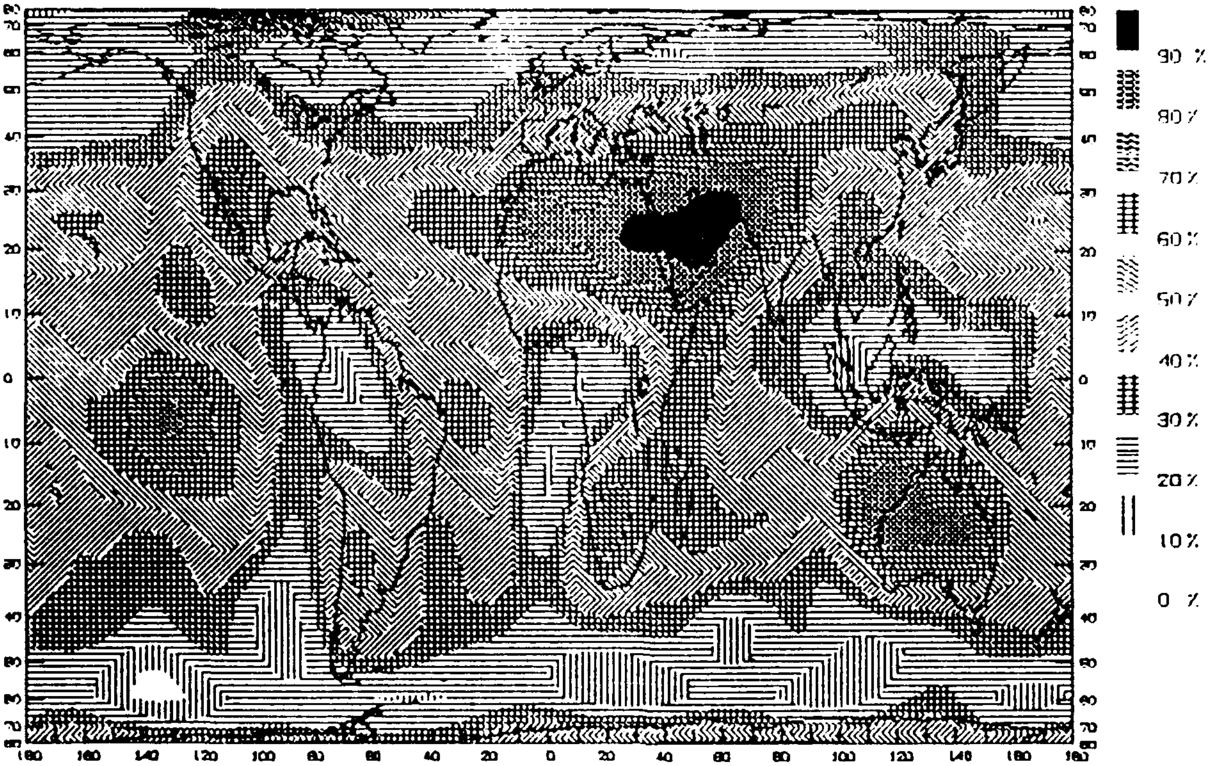

Figure 8a.

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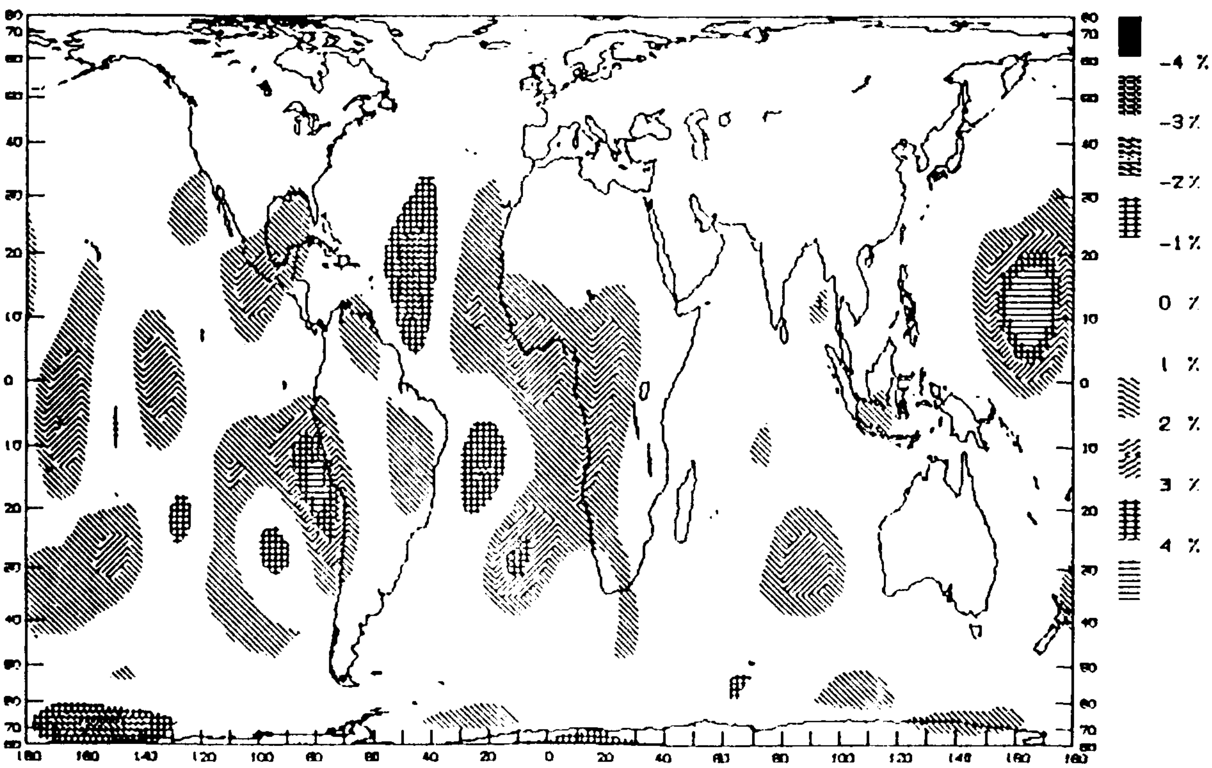

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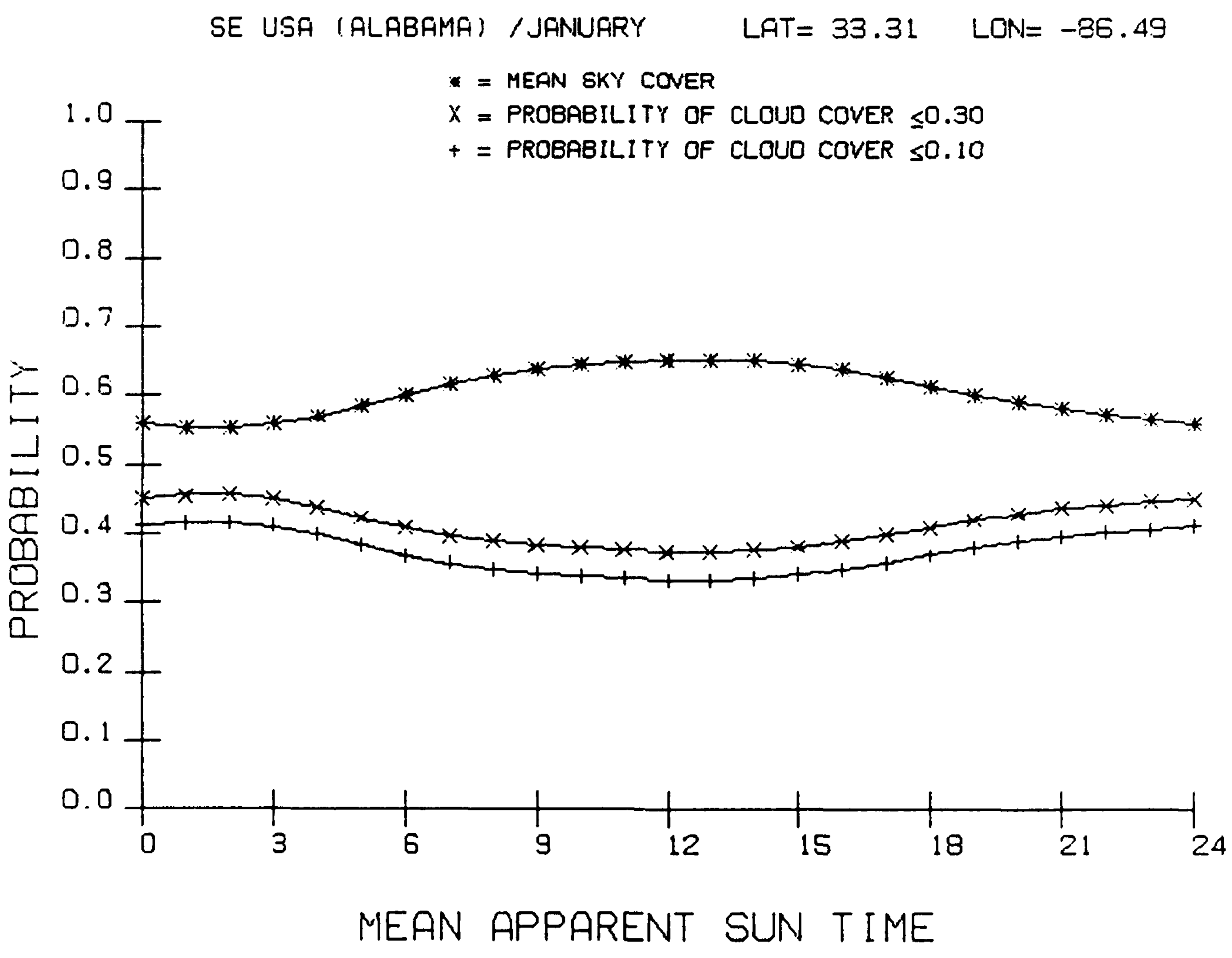
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MEAN APPARENT SUN TIME

Figure 9.

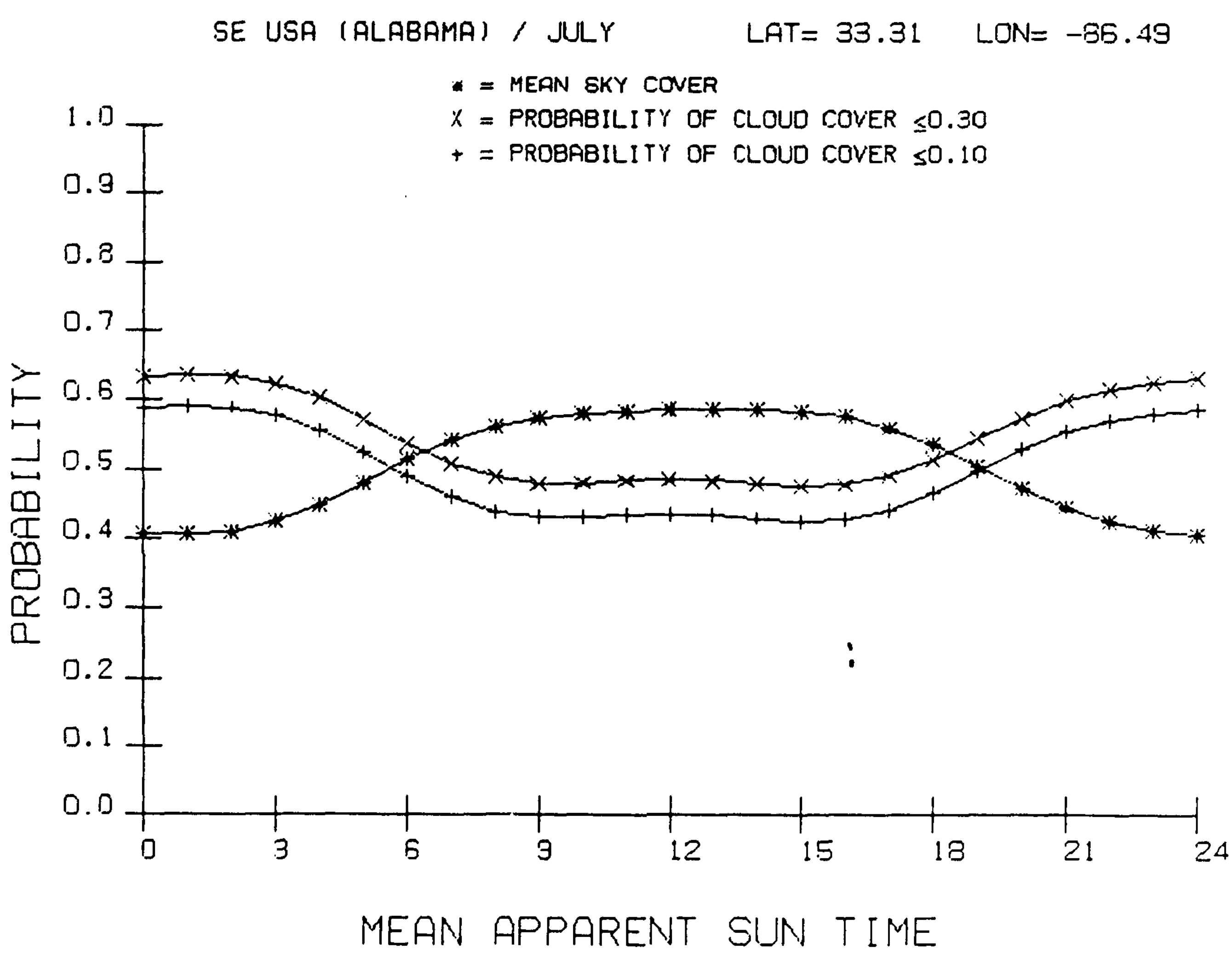
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Figure 10.

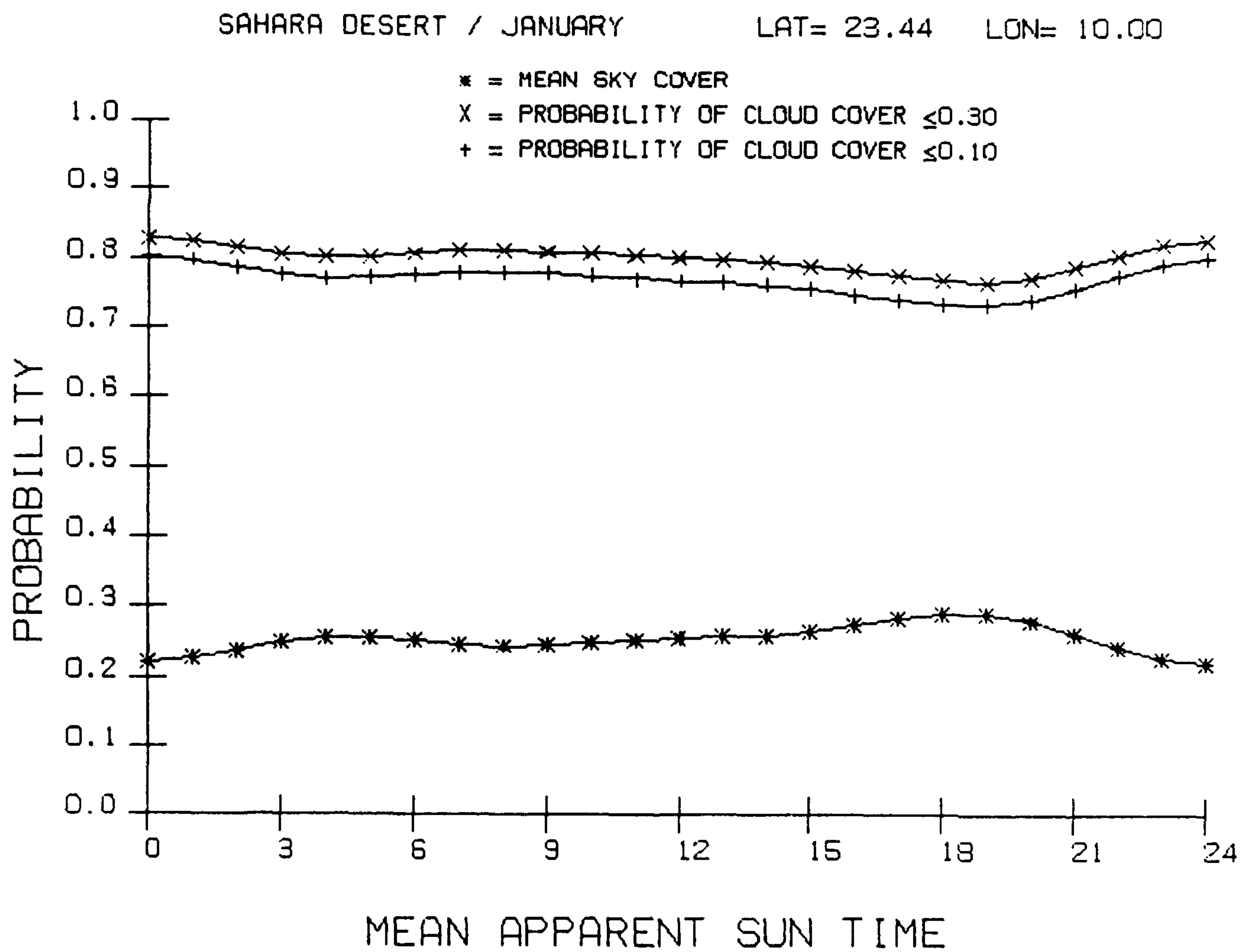
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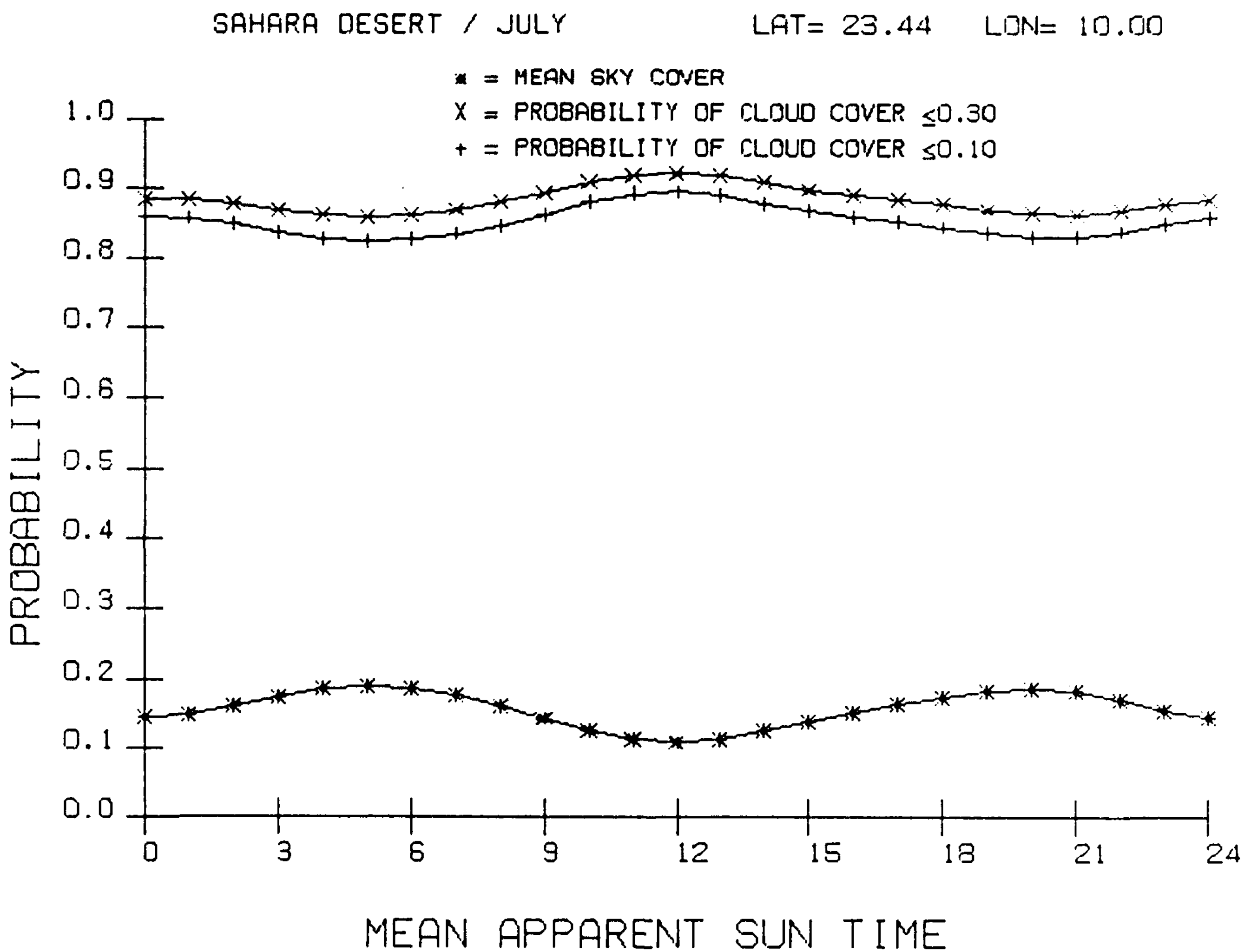
Figure 11.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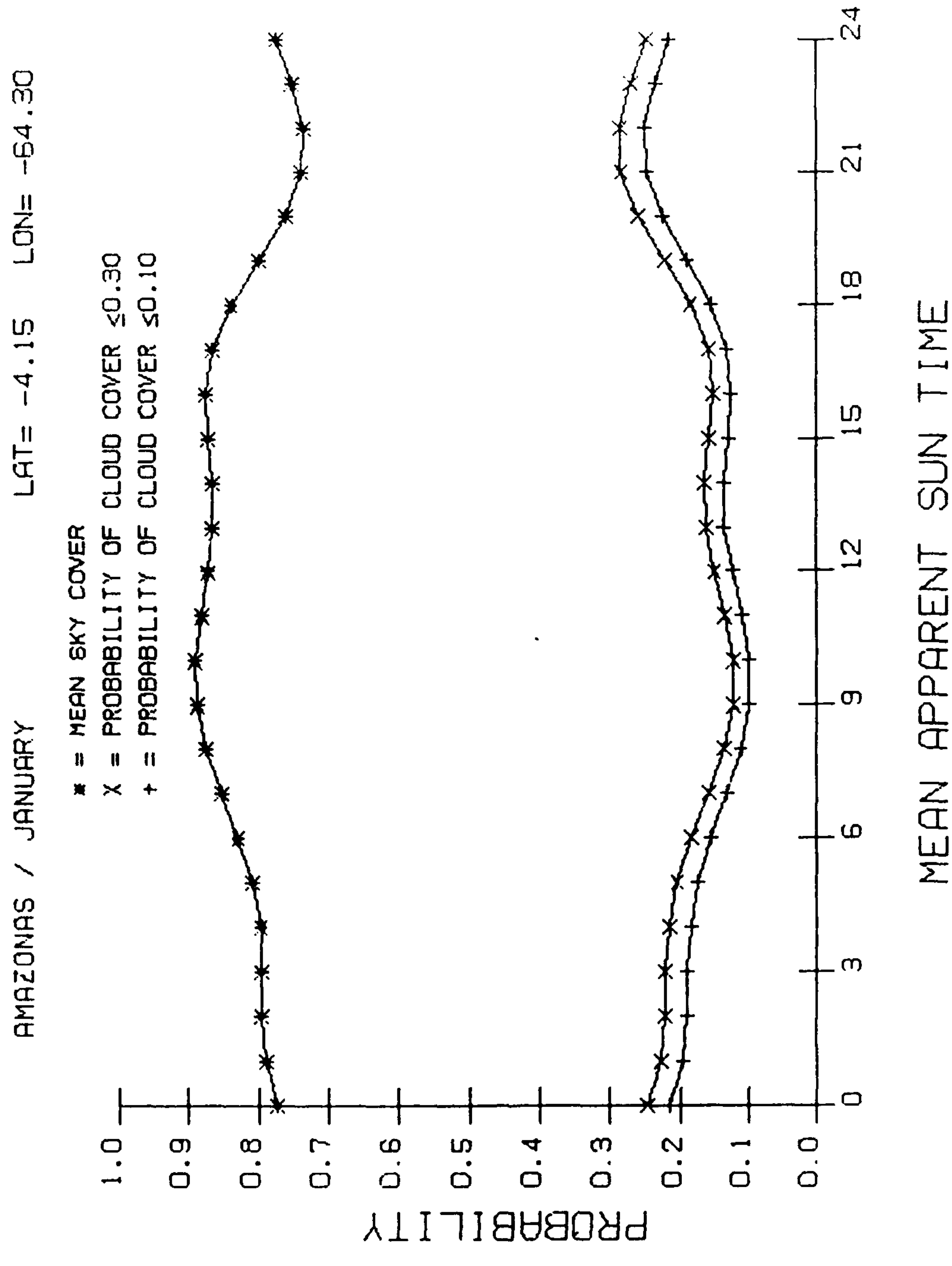
MEAN APPARENT SUN TIME

Figure 12.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MEAN APPARENT SUN TIME

Figure 13.

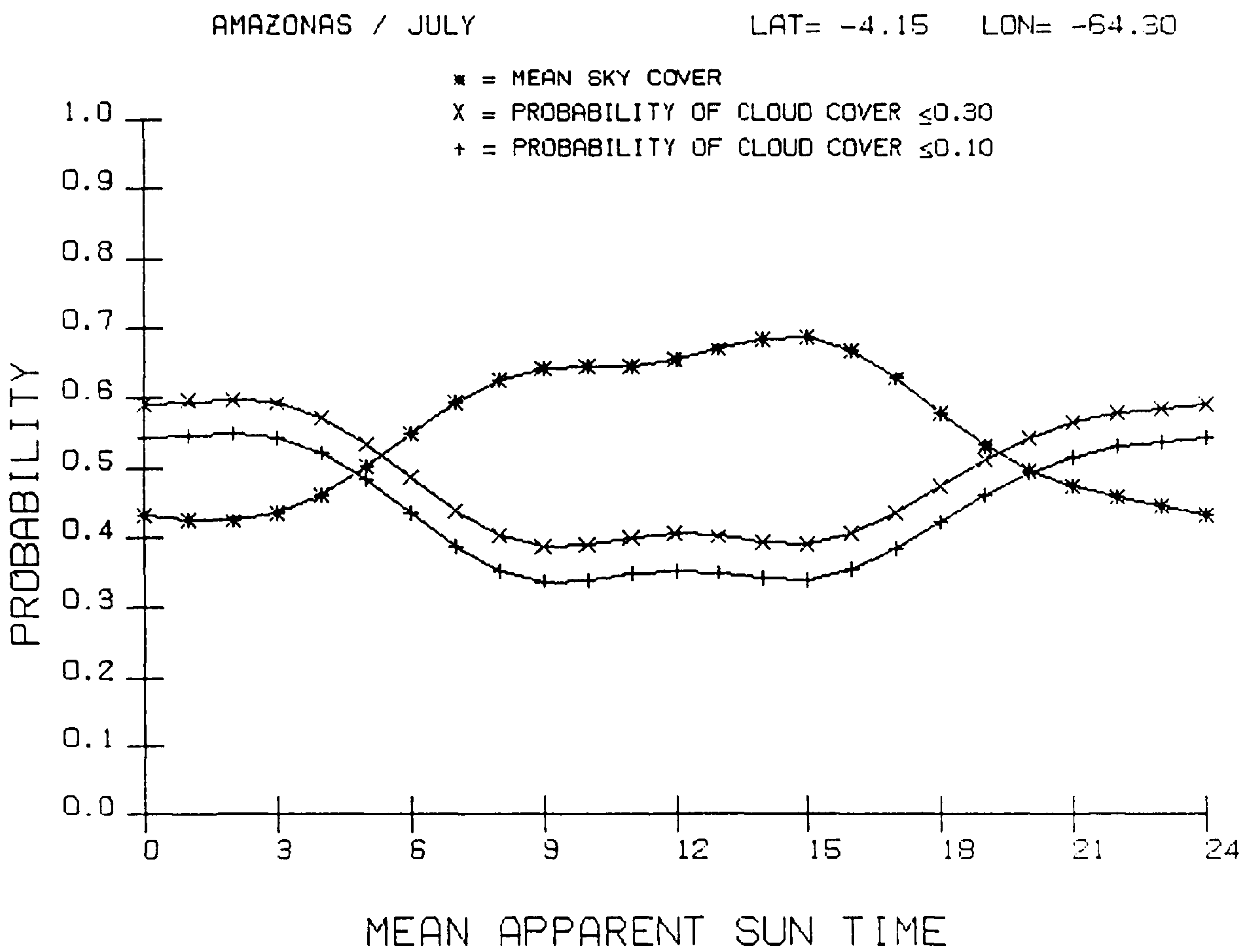

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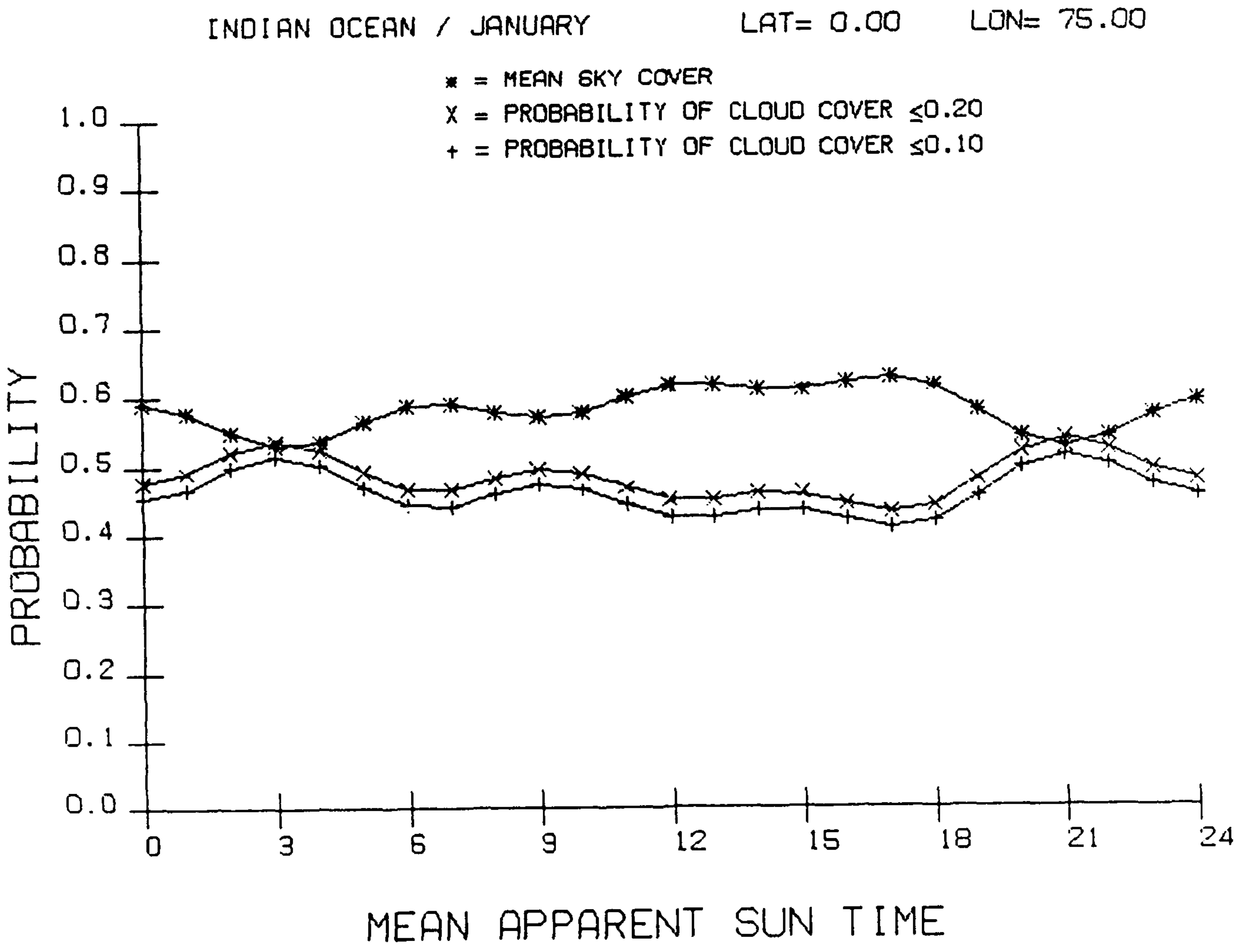
Figure 14.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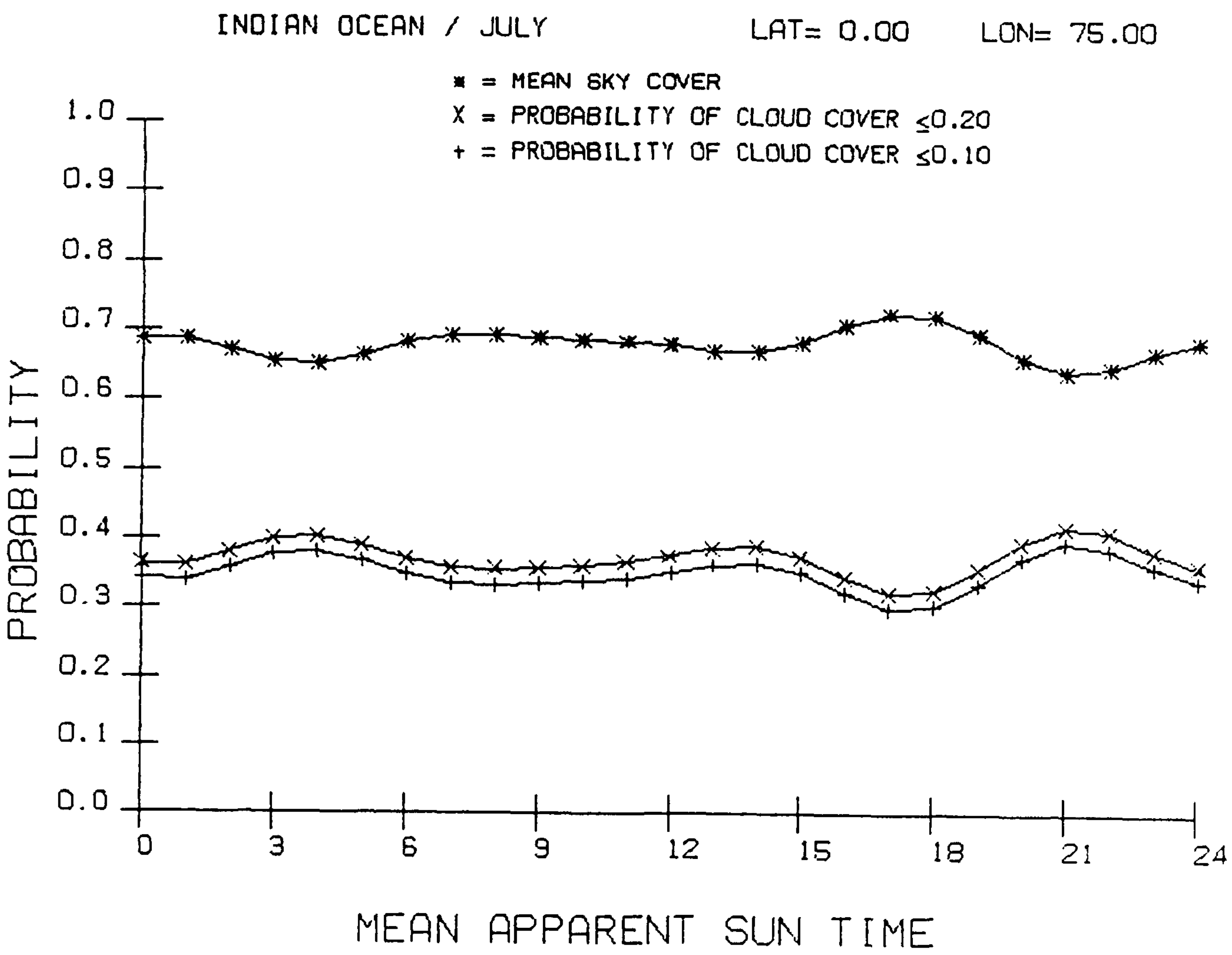
9
12
15
18
21
24
MEAN APPARENT SUN TIME

Figure 15.



INDIAN OCEAN / JULY
LAT= 0.00
LON= 75.00
* = MEAN SKY COVER
X = PROBABILITY OF CLOUD COVER ≤0.20
+ = PROBABILITY OF CLOUD COVER ≤0.10
PROBABILITY
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
3
6
9
12
15
18
21
24
MEAN APPARENT SUN TIME

Figure 16.

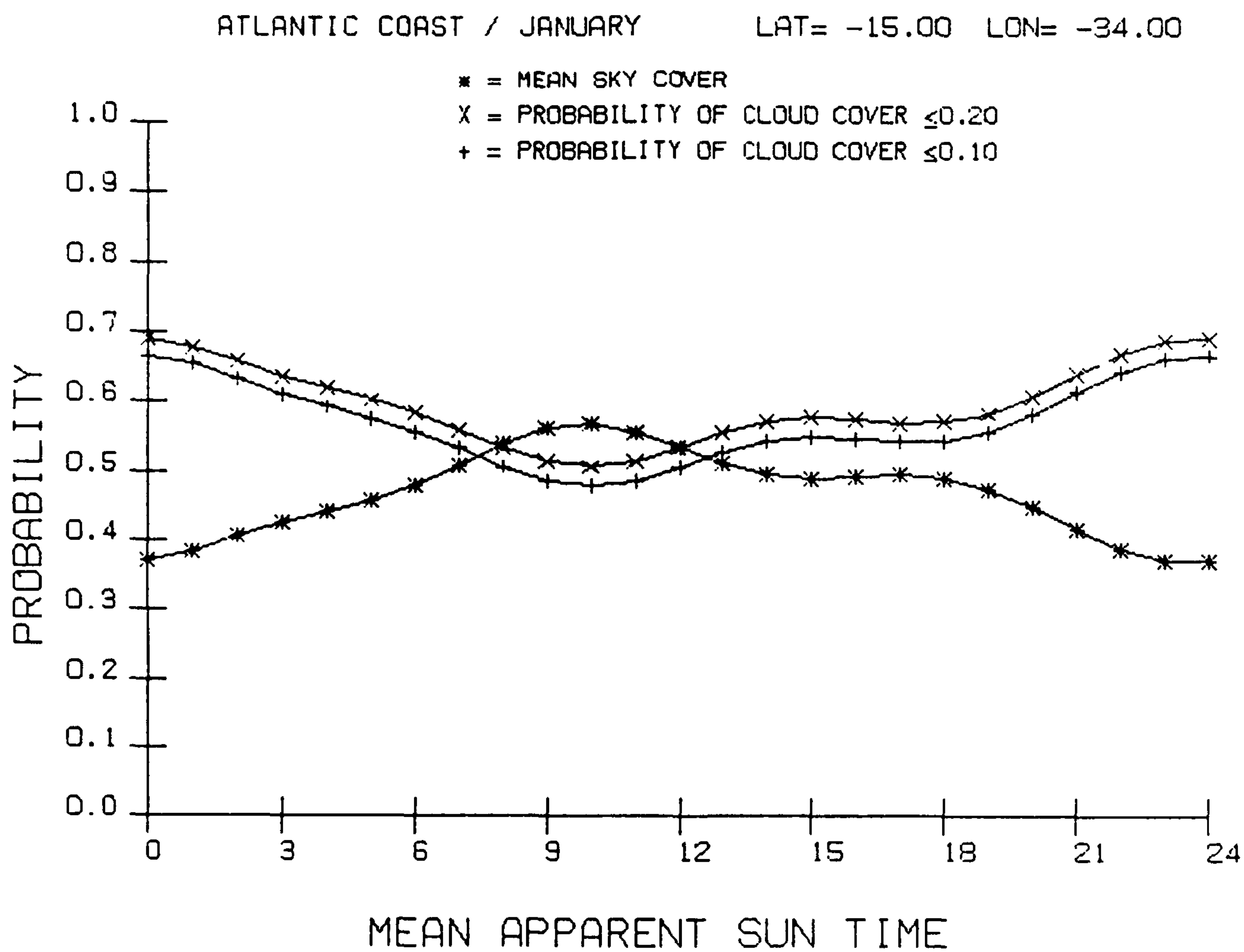

ATLANTIC COAST / JANUARY LAT= -15.00 LON= -34.00
* = MEAN SKY COVER
X = PROBABILITY OF CLOUD COVER ≤0.20
+ = PROBABILITY OF CLOUD COVER ≤0.10
PROBABILITY
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
3
6
9
12
15
18
21
24
MEAN APPARENT SUN TIME

Figure 17.

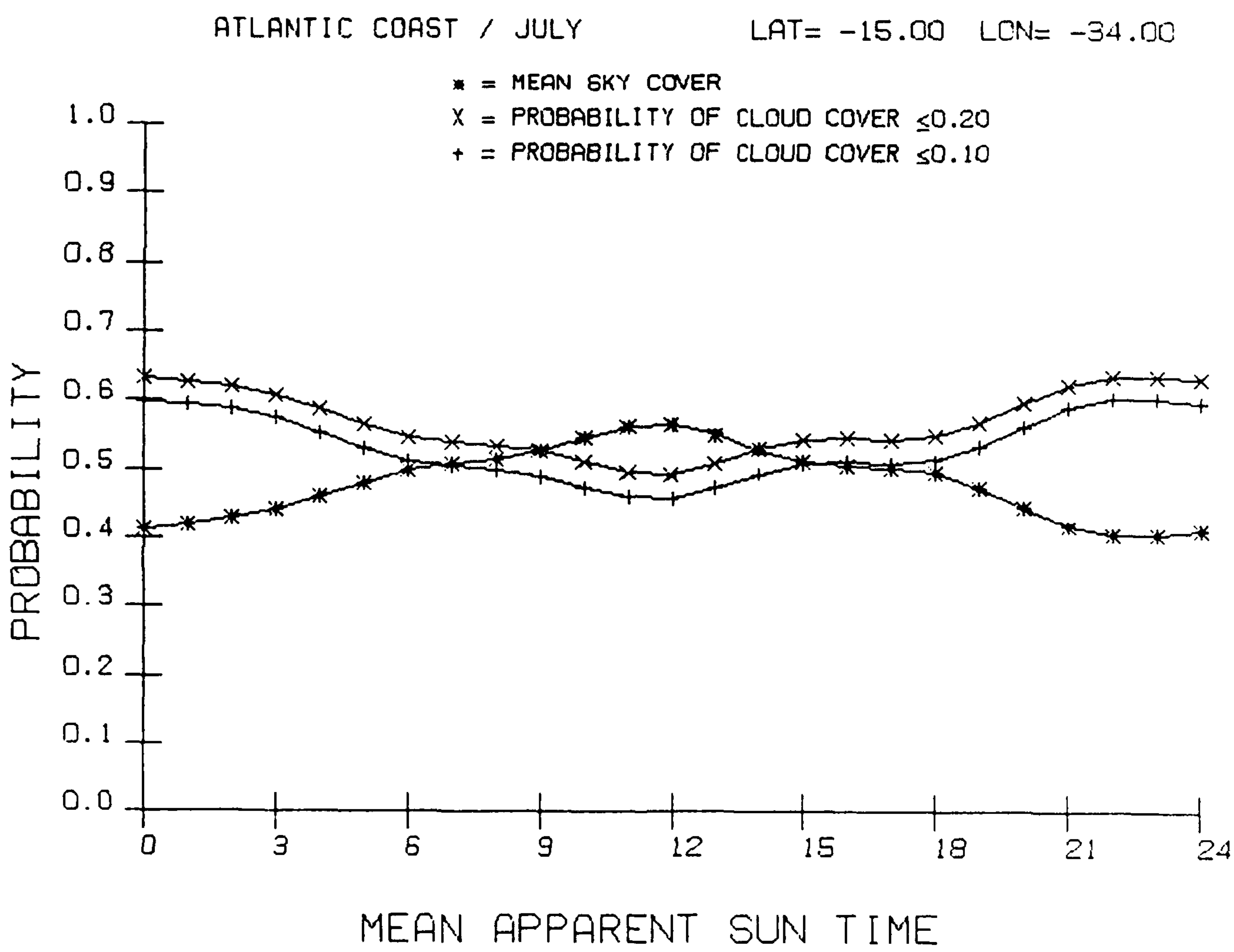

ATLANTIC COAST / JULY
LAT= -15.00 LON= -34.00
* = MEAN SKY COVER
X = PROBABILITY OF CLOUD COVER ≤0.20
+ = PROBABILITY OF CLOUD COVER ≤0.10
PROBABILITY
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
3
6
9
12
15
18
21
24
MEAN APPARENT SUN TIME

Figure 18.

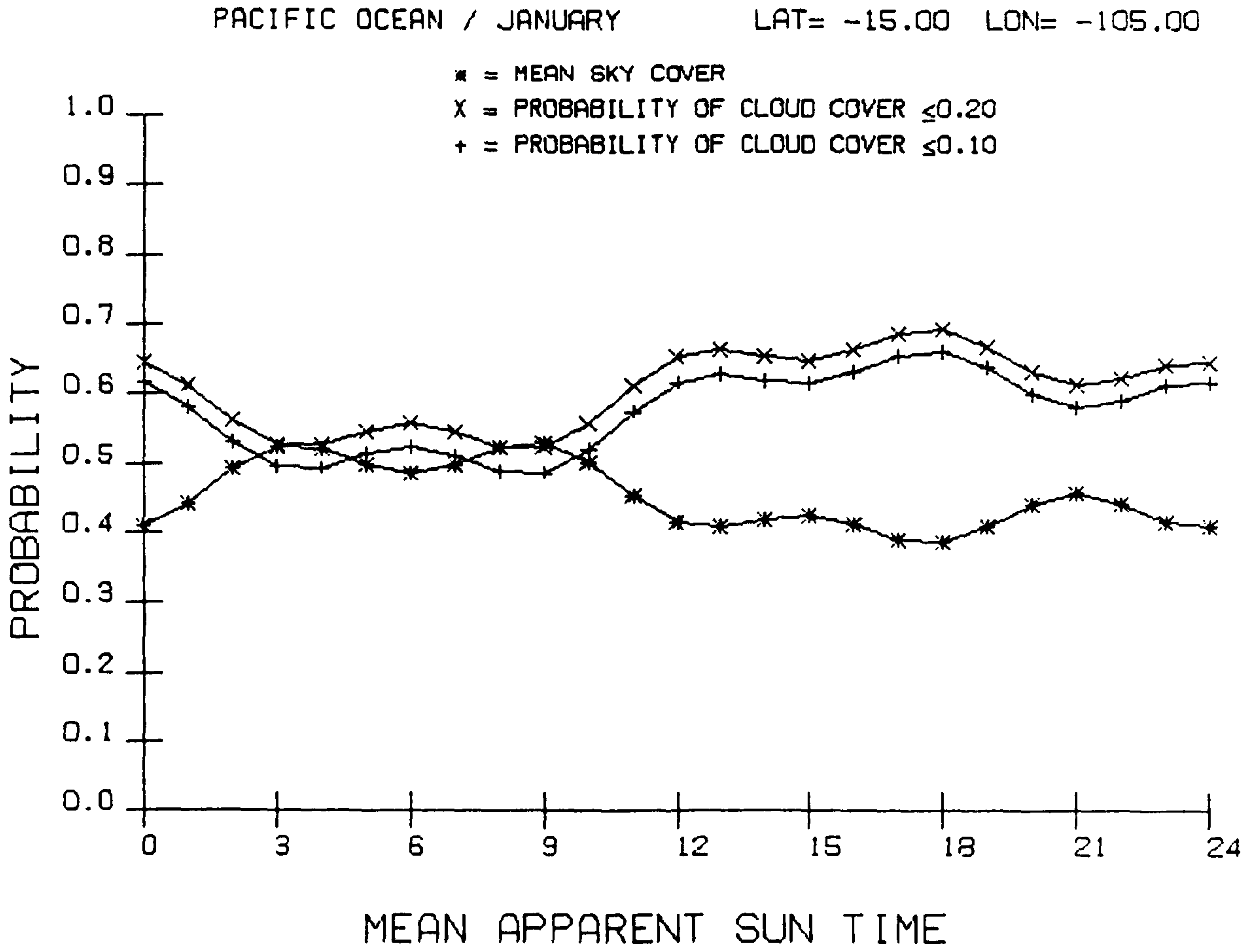

PACIFIC OCEAN / JANUARY LAT= -15.00 LON= -105.00
* = MEAN SKY COVER
X = PROBABILITY OF CLOUD COVER ≤0.20
+ = PROBABILITY OF CLOUD COVER ≤0.10
PROBABILITY
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
3
6
9
12
15
18
21
24
MEAN APPARENT SUN TIME

Figure 19.

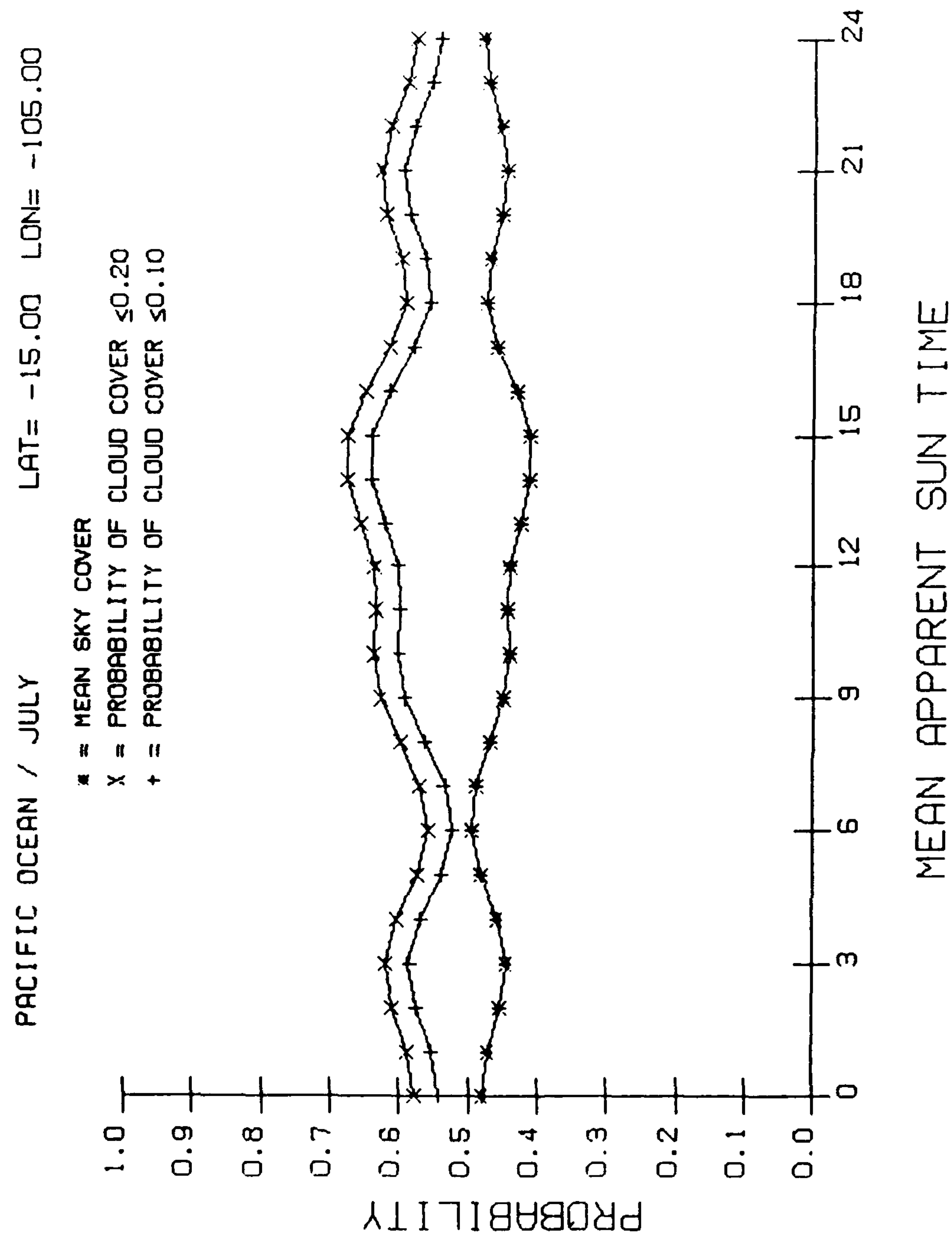

PACIFIC OCEAN / JULY
LAT= -15.00 LON= -105.00
* = MEAN SKY COVER
X = PROBABILITY OF CLOUD COVER ≤0.20
+ = PROBABILITY OF CLOUD COVER ≤0.10
PROBABILITY
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
3
6
9
12
15
18
21
24
MEAN APPARENT SUN TIME

Figure 20.

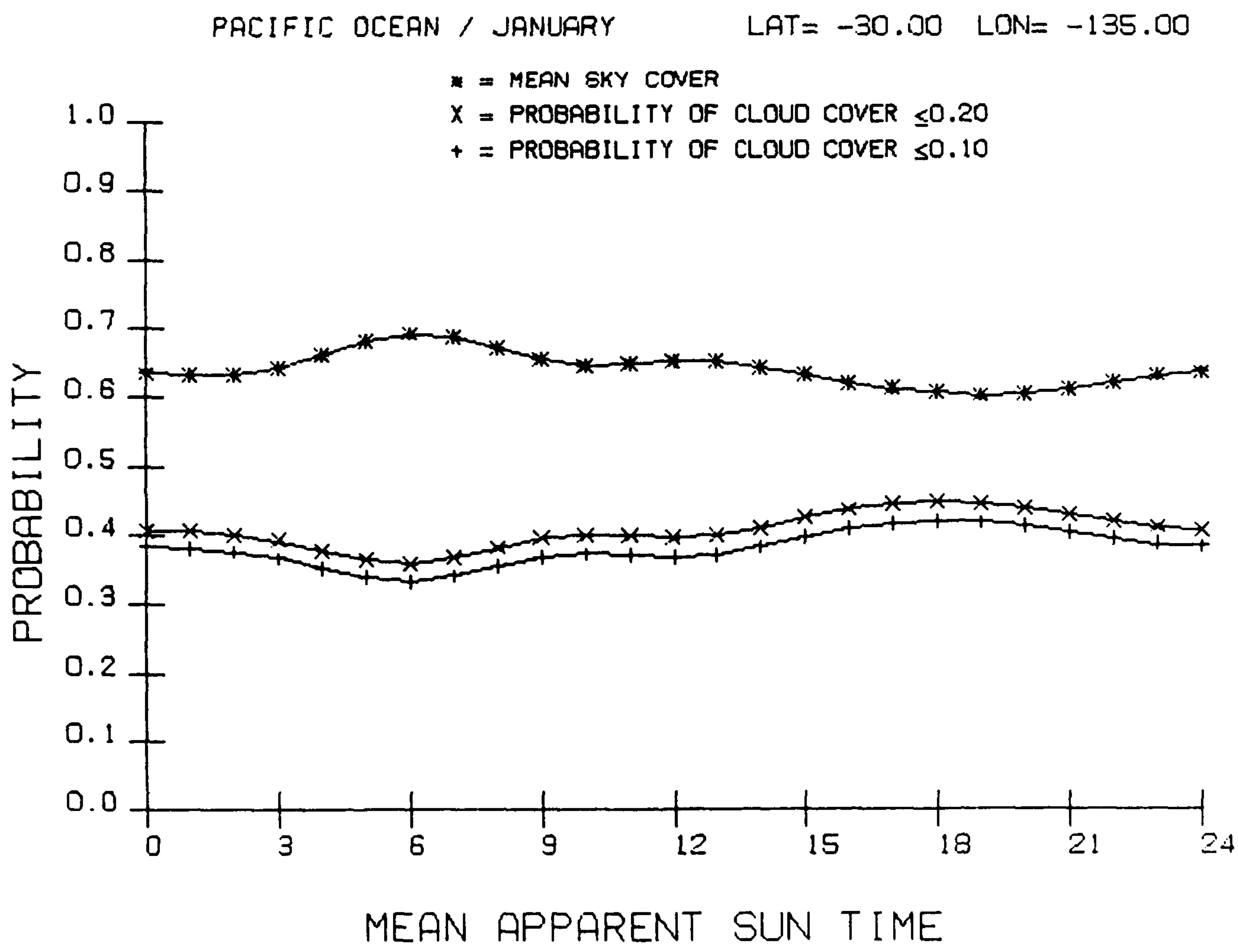

PACIFIC OCEAN / JANUARY
LAT= -30.00 LON= -135.00
* = MEAN SKY COVER
X = PROBABILITY OF CLOUD COVER ≤0.20
+ = PROBABILITY OF CLOUD COVER ≤0.10
PROBABILITY
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
3
6
9
12
15
18
21
24
MEAN APPARENT SUN TIME

Figure 21.

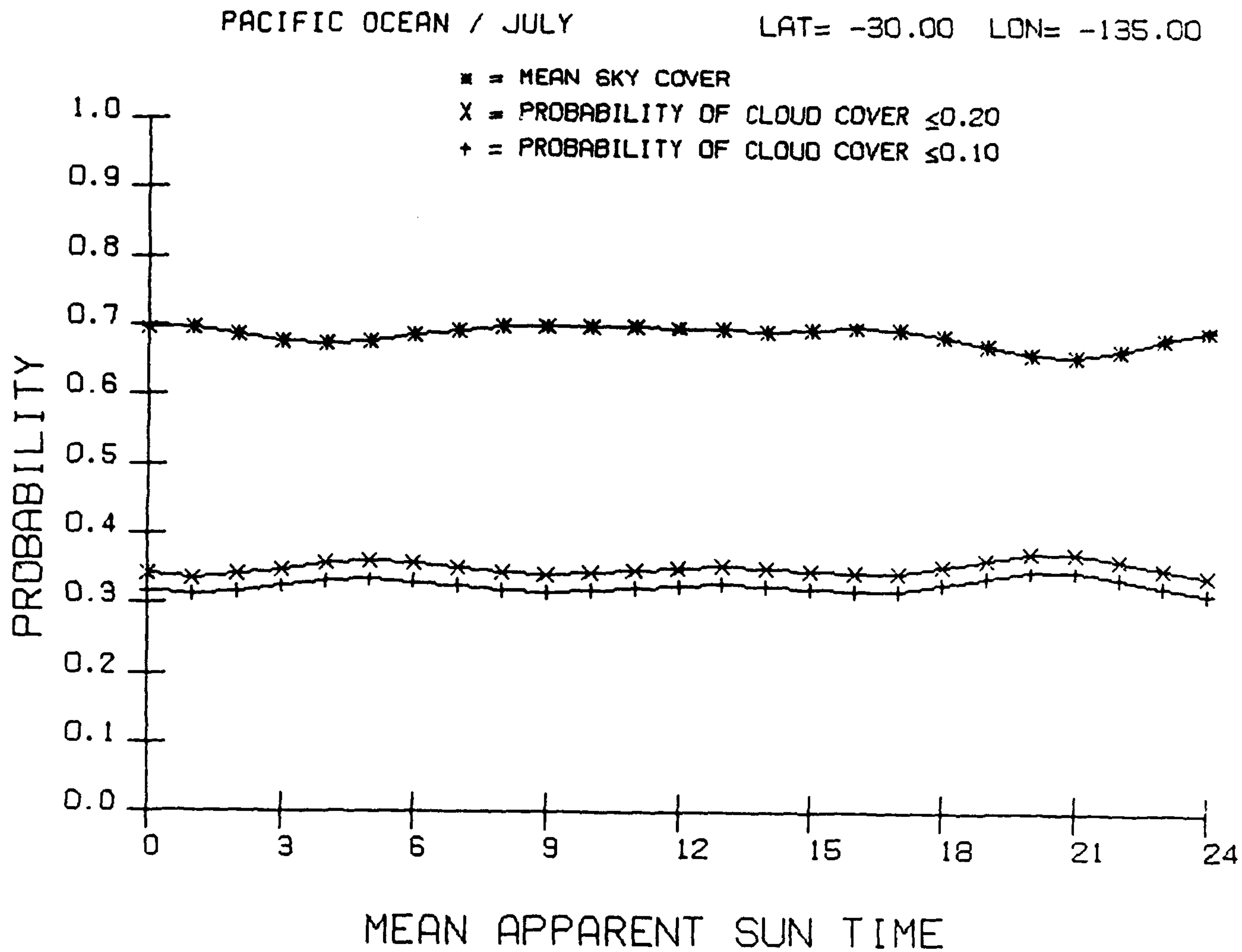

PACIFIC OCEAN / JULY
LAT= -30.00 LON= -135.00
* = MEAN SKY COVER
X = PROBABILITY OF CLOUD COVER ≤0.20
+ = PROBABILITY OF CLOUD COVER ≤0.10
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
PROBABILITY
0
3
6
9
12
15
18
21
24
MEAN APPARENT SUN TIME

Figure 22.

Table 1.0

LANDSAT TIME OFFSET					
(From Local Mean Apparant Solar Time - Desc. Node Crossing)					
LATITUDE °		TIME ADJ mins.			
81.79		359.237			
81		262.253			
80		219.803			
79		191.453			
78		170.957			
77		154.483			
76		141.473			
75		130.167			
74		120.803			
73		112.537			
72		105.397			
71		98.993			
70		93.380			
65		72.057			
60		57.890			
50		39.643			
40		27.803			
30		19.107			
20		12.050			
10		5.833			
0		±0.000			
-10		-5.817			
-20		-12.033			
-30		-19.107			
-40		-27.787			
-50		-39.587			
-60		-57.817			
-65		-72.007			
-70		-93.403			
-71		-99.023			
-72		-105.390			
-73		-112.527			
-74		-120.753			
-75		-130.357			
-76		-141.303			
-77		-154.633			
-78		-171.067			
-79		-191.507			
-80		-219.737			
-81		-261.987			
-81.79		-359.490			